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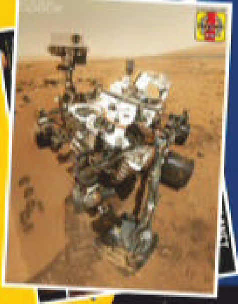

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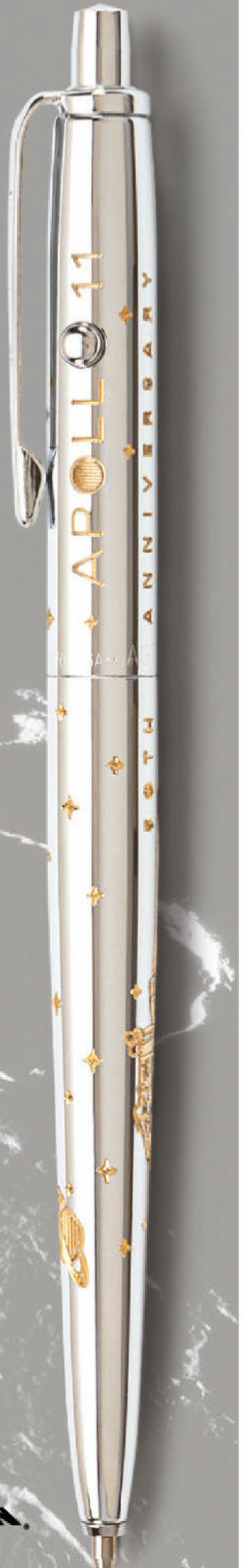

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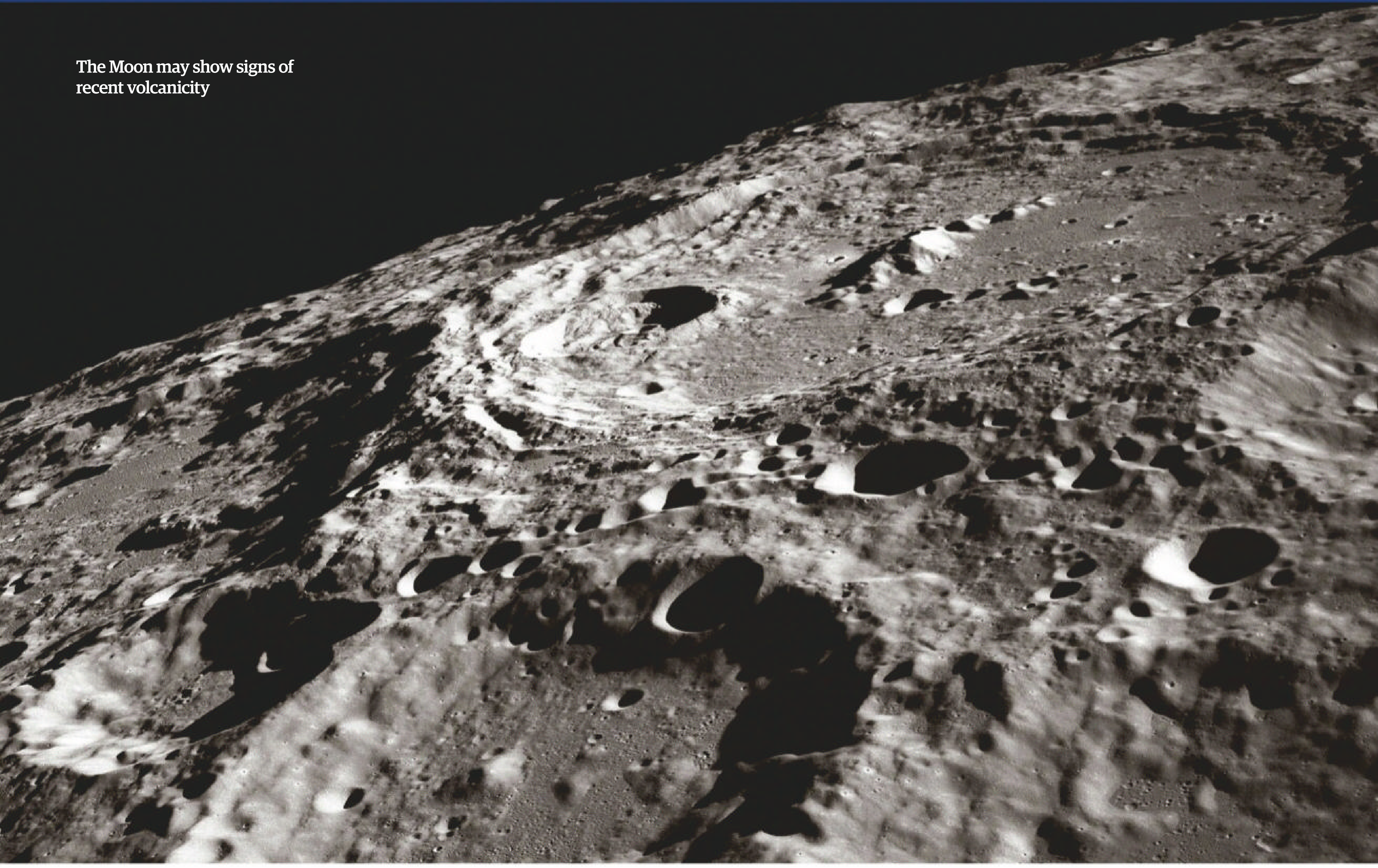
The Moon may show signs of recent volcanicity

Welcome

The European Space Agency has recently announced a brand-new ambitious mission to an interstellar object, making its way through our Solar System. They call it the Comet Interceptor. This issue we chat to the scientists behind the mission on what we can expect when the mission launches in 2028.

Granted, that's quite a while away yet, but the excitement of a mission that's set to echo the achievements of mechanical duo Rosetta and Philae, which completed one tricky manoeuvre after another in order to successfully visit and study Comet 67P/Churyumov-Gerasimenko up close in 2014, is prevalent - what will we find when we visit an interstellar world? Comet Interceptor could be the spacecraft to reveal the secrets of the Solar System's origin once and for all. Turn to page 16 for space science reporter Jonathan O'Callaghan's full report.

Also this issue, we uncover who really killed 16th-century astronomer Tycho Brahe - did natural causes claim his life or was it something much more sinister? Historians have placed associate and fellow observer Johannes Kepler firmly in the frame - but there are other suspects, as you'll discover over on page 38.

We've also teamed up with Haynes Manuals and Space Rocks this month to bring you a free poster with this issue as well as some exclusive gifts with your magazine subscription. Enjoy the issue!

Gemma Lavender
Editor-in-Chief

Our contributors include...

Giles Sparrow
Space science writer
Astronomer Tycho Brahe died under suspicious circumstances – this issue, historians believe that they've finally solved the case

James Romero
Space science writer
Our Moon is much more alive than we originally thought. James reveals the water and volcanic activity found by NASA and ISRO spacecraft

Lee Cavendish
Staff Writer
Our views of the Red Planet have changed dramatically in recent years. Lee presents the new discoveries that have turned our theories on their head

Alberto Dominguez
Astrophysicist
Alberto provides a five-minute masterclass on Einstein's equation linking mass and energy, the century-old $E=mc^2$

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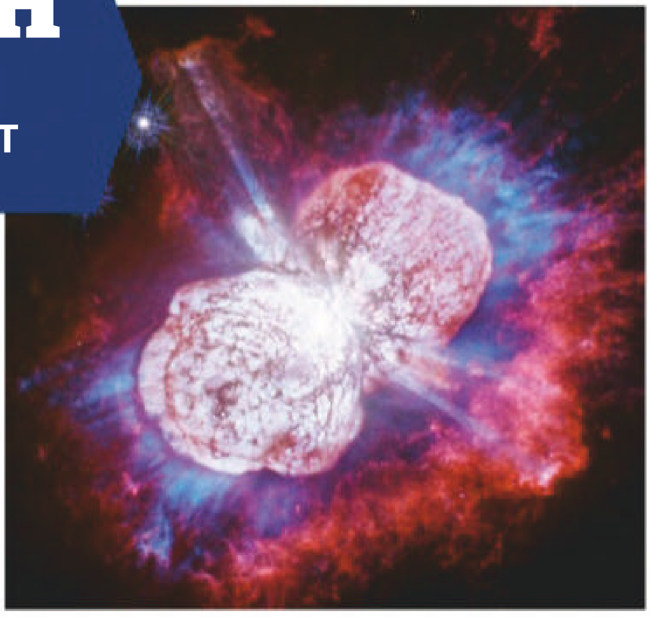

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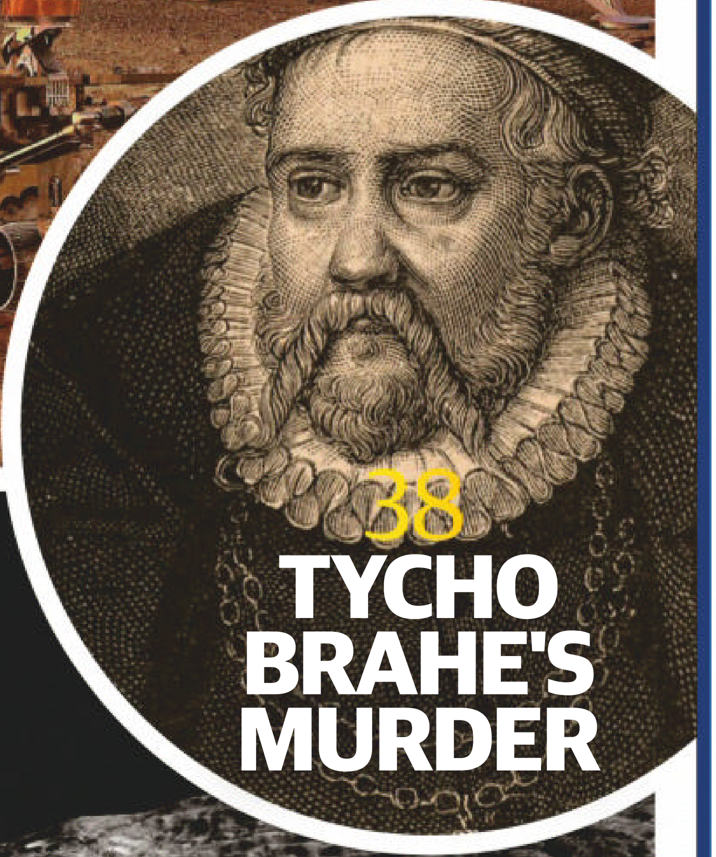

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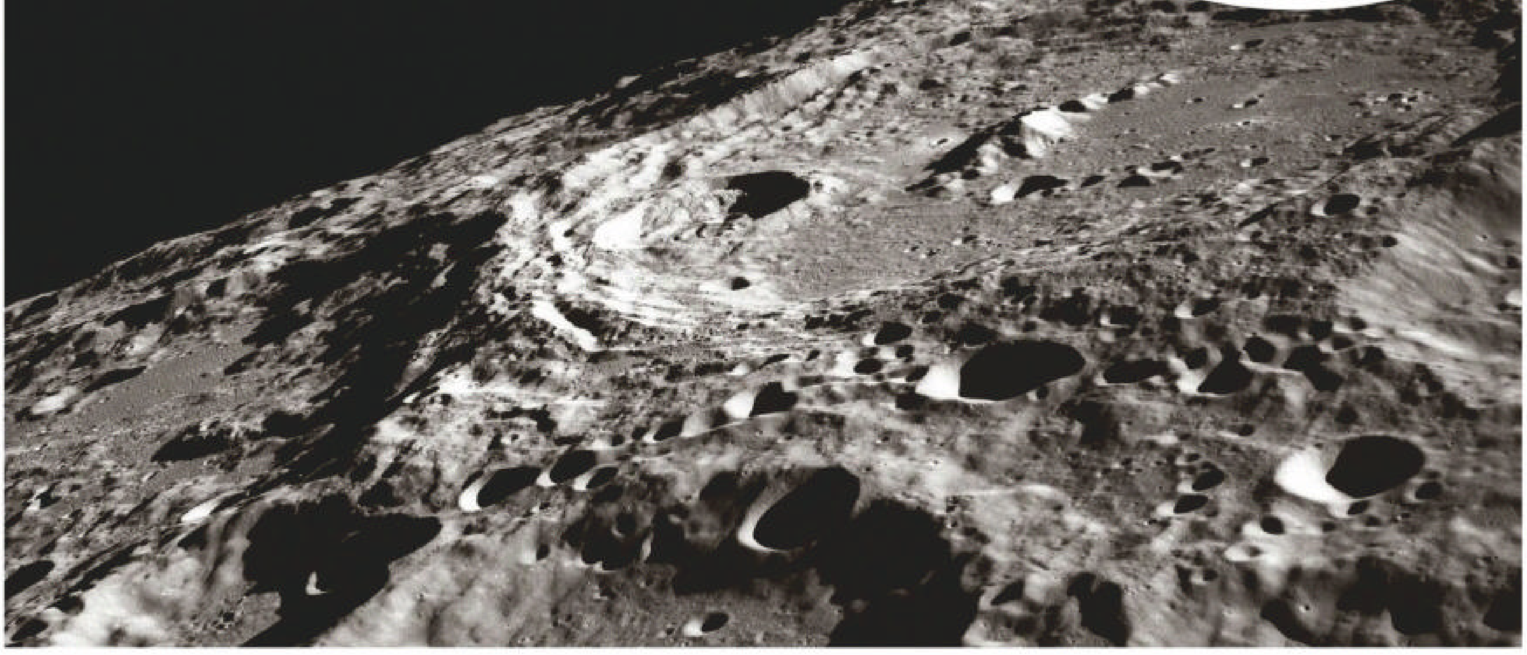

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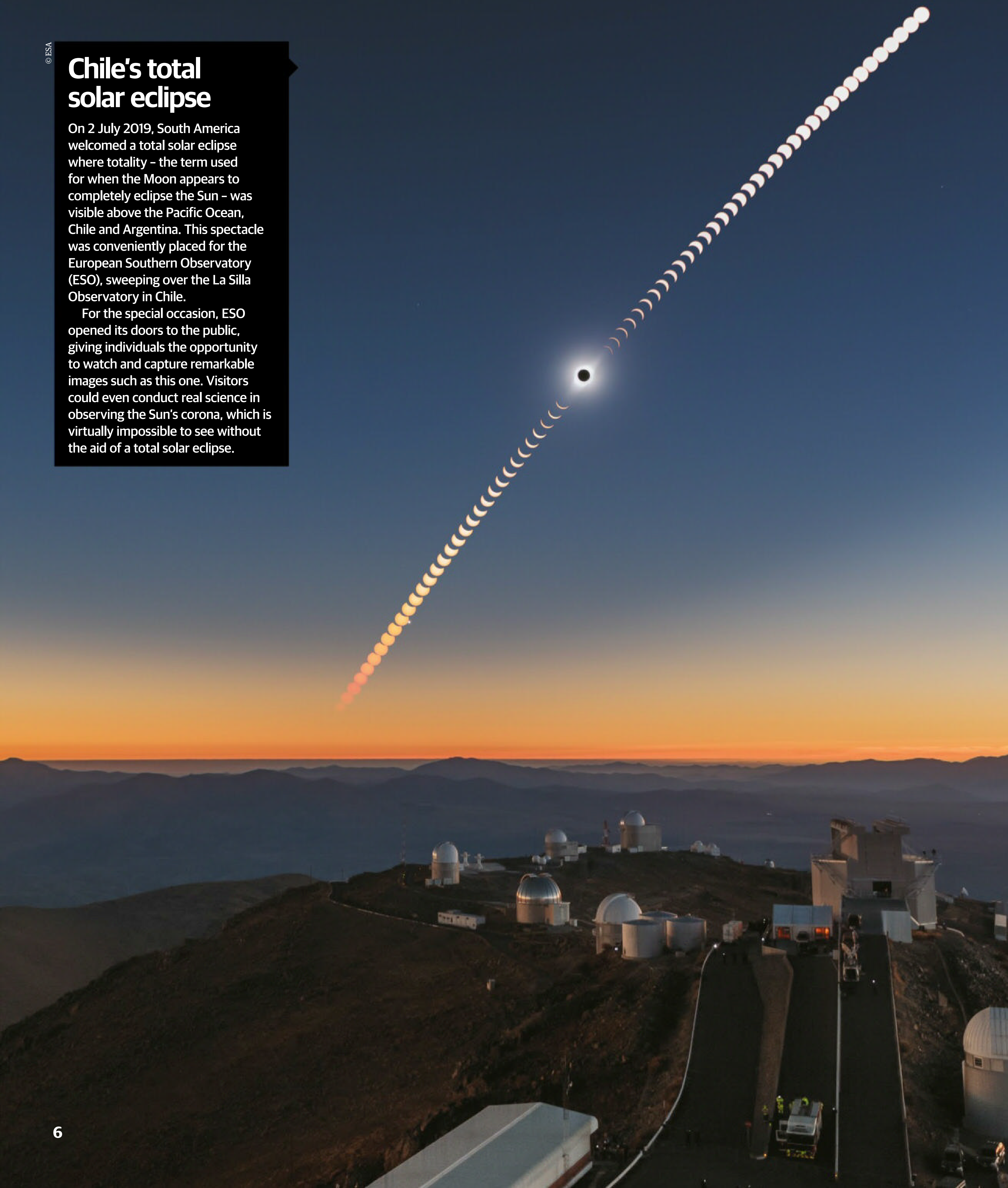

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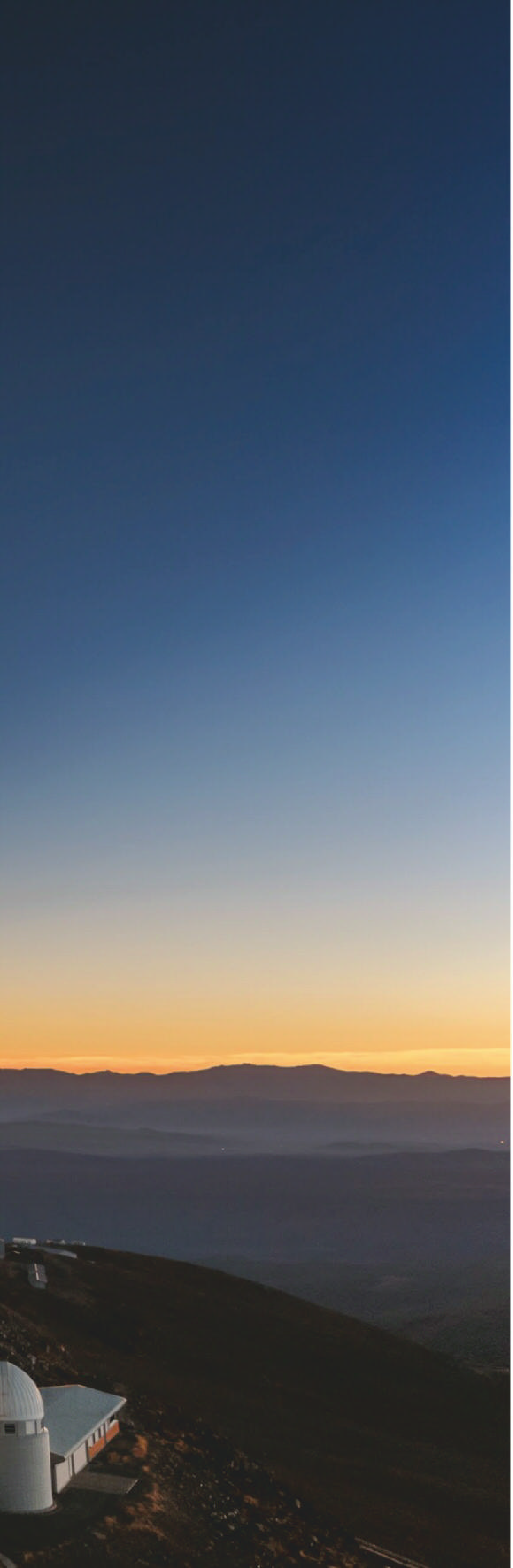
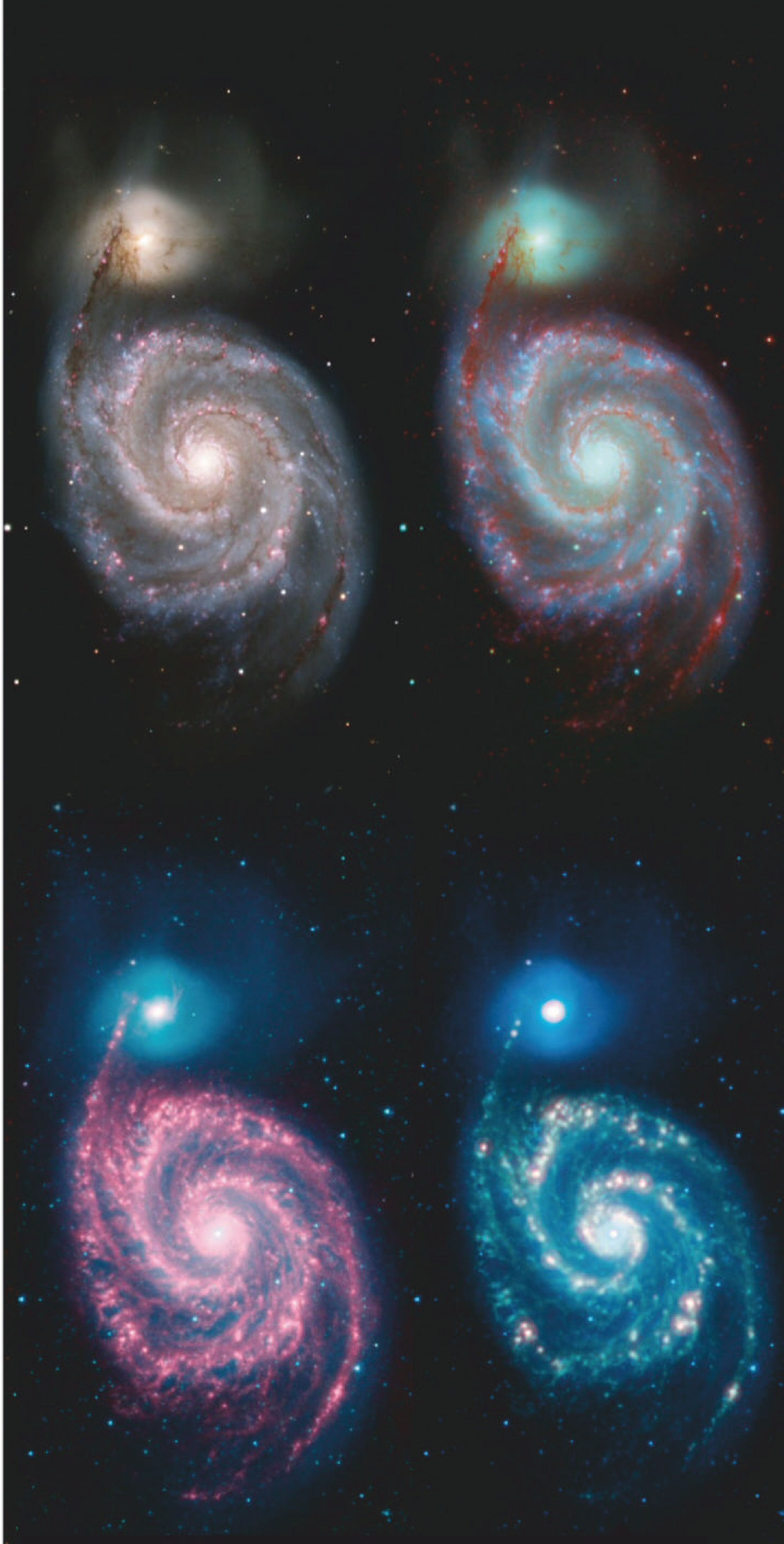
Chile's total solar eclipse

On 2 July 2019, South America welcomed a total solar eclipse where totality – the term used for when the Moon appears to completely eclipse the Sun – was visible above the Pacific Ocean, Chile and Argentina. This spectacle was conveniently placed for the European Southern Observatory (ESO), sweeping over the La Silla Observatory in Chile.

For the special occasion, ESO opened its doors to the public, giving individuals the opportunity to watch and capture remarkable images such as this one. Visitors could even conduct real science in observing the Sun's corona, which is virtually impossible to see without the aid of a total solar eclipse.





Spitzer or Warhol?

If Andy Warhol had been an astronomer, this would almost certainly be a piece of his work. This image is reminiscent of his famous silkscreen grids of the same image repeated in different colours, but the space-borne artist on this occasion is the Spitzer Space Telescope – and it has 'painted' the Whirlpool Galaxy (M51) in a variety of different wavelengths.

The pair of waltzing galaxies that comprise M51 are shown in visible light, blue and green visible light wavelengths and infrared at 3.6 microns. Meanwhile, the bottom right-hand image shows the Whirlpool Galaxy in infrared at 24 microns.

© NASA/JPL-Caltech

The star that once shined so bright

Hubble was once again on form as it captured another magnificent sight from the depths of the universe. This time, it snapped some stellar fireworks as the enormous, unstable star known as Eta Carinae continues to expel its contents into the cosmos.

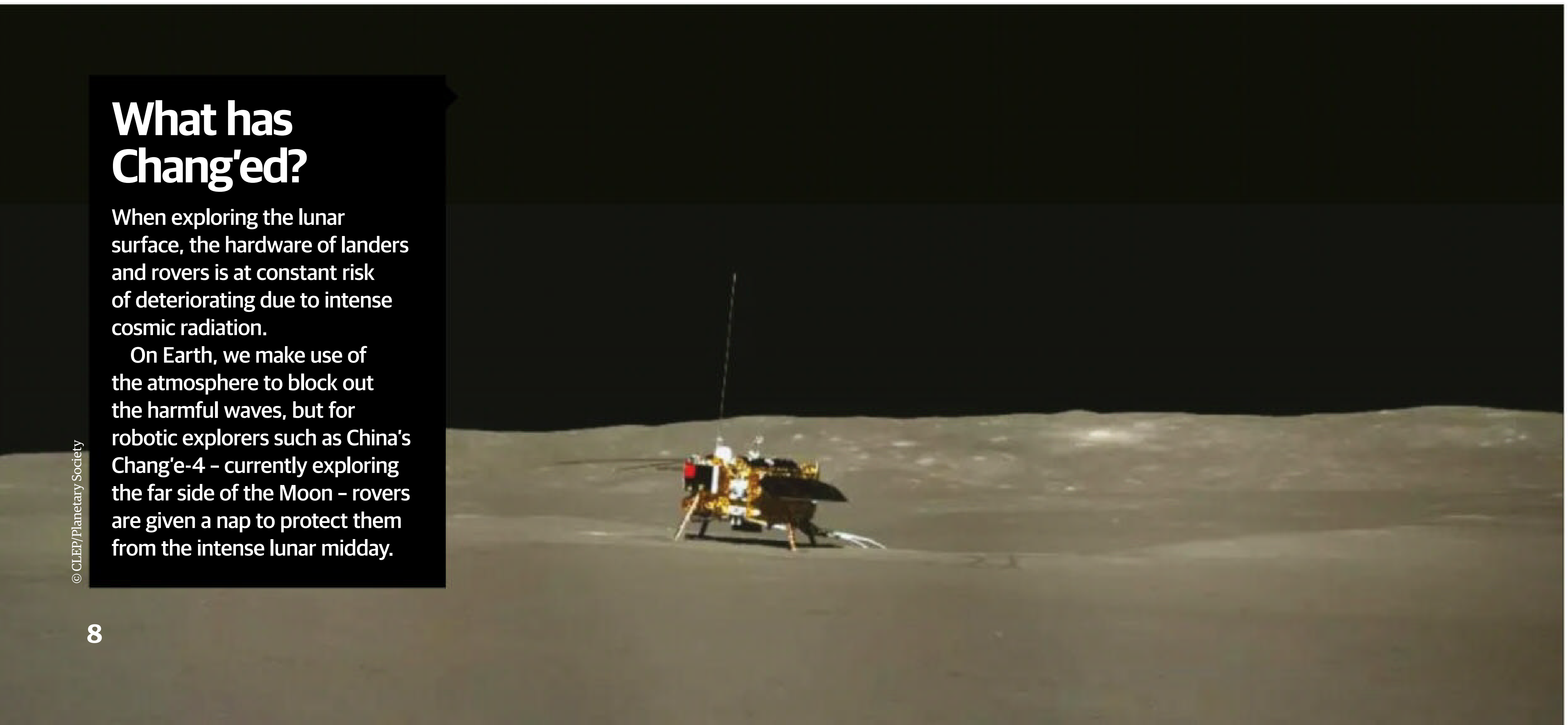
The double-star system Eta Carinae has been oozing hot gas and dust since the 1840s. In fact, when it first erupted, it was the second-brightest star in the night sky for a decade. These days though, it is not as noticeable in the night sky – but Hubble did a marvellous job in capturing its colourful contrast in vibrant and energetic ultraviolet.

© NASA/ESA

What has Chang'ed?

When exploring the lunar surface, the hardware of landers and rovers is at constant risk of deteriorating due to intense cosmic radiation.

On Earth, we make use of the atmosphere to block out the harmful waves, but for robotic explorers such as China's Chang'e-4 – currently exploring the far side of the Moon – rovers are given a nap to protect them from the intense lunar midday.



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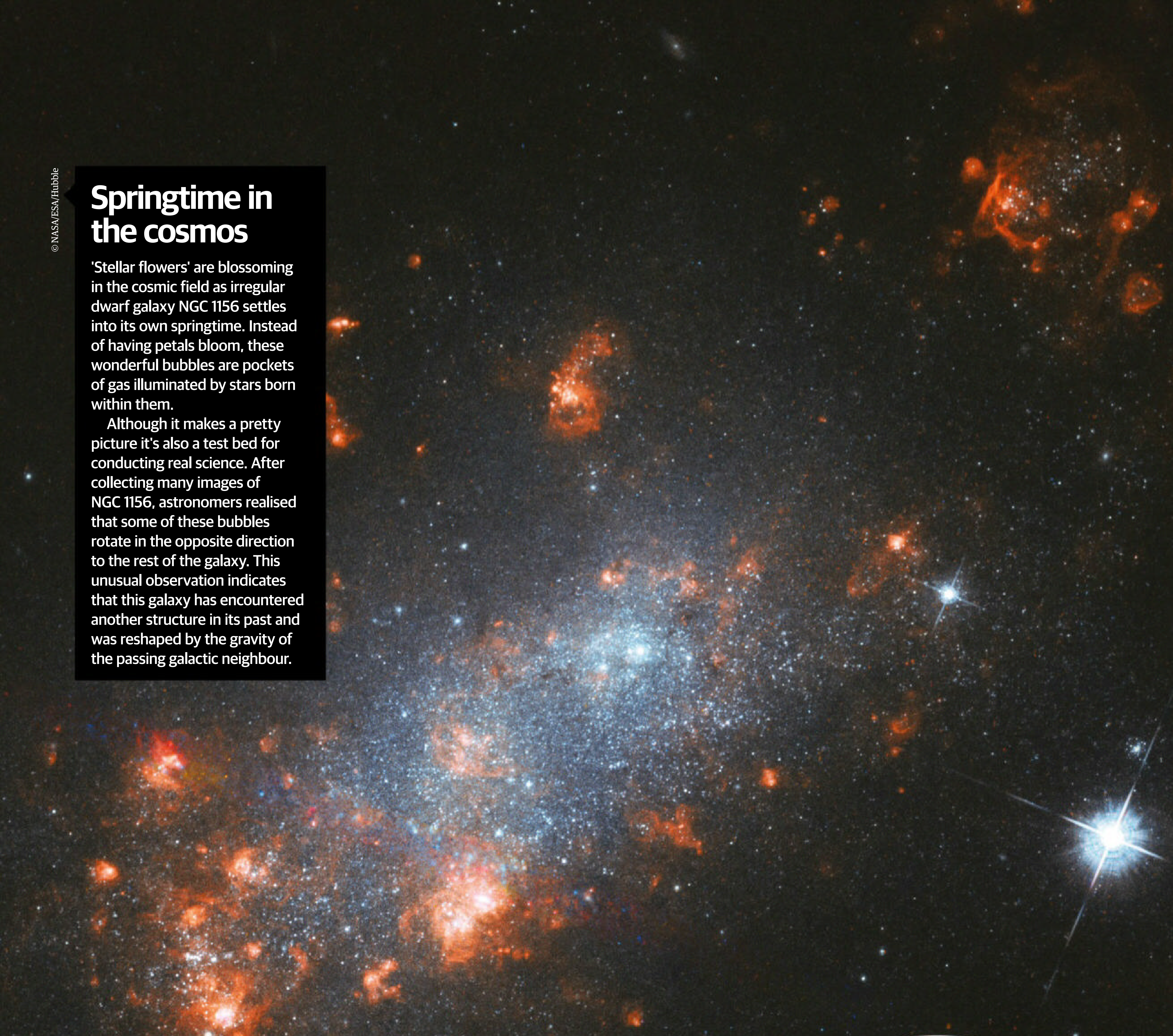
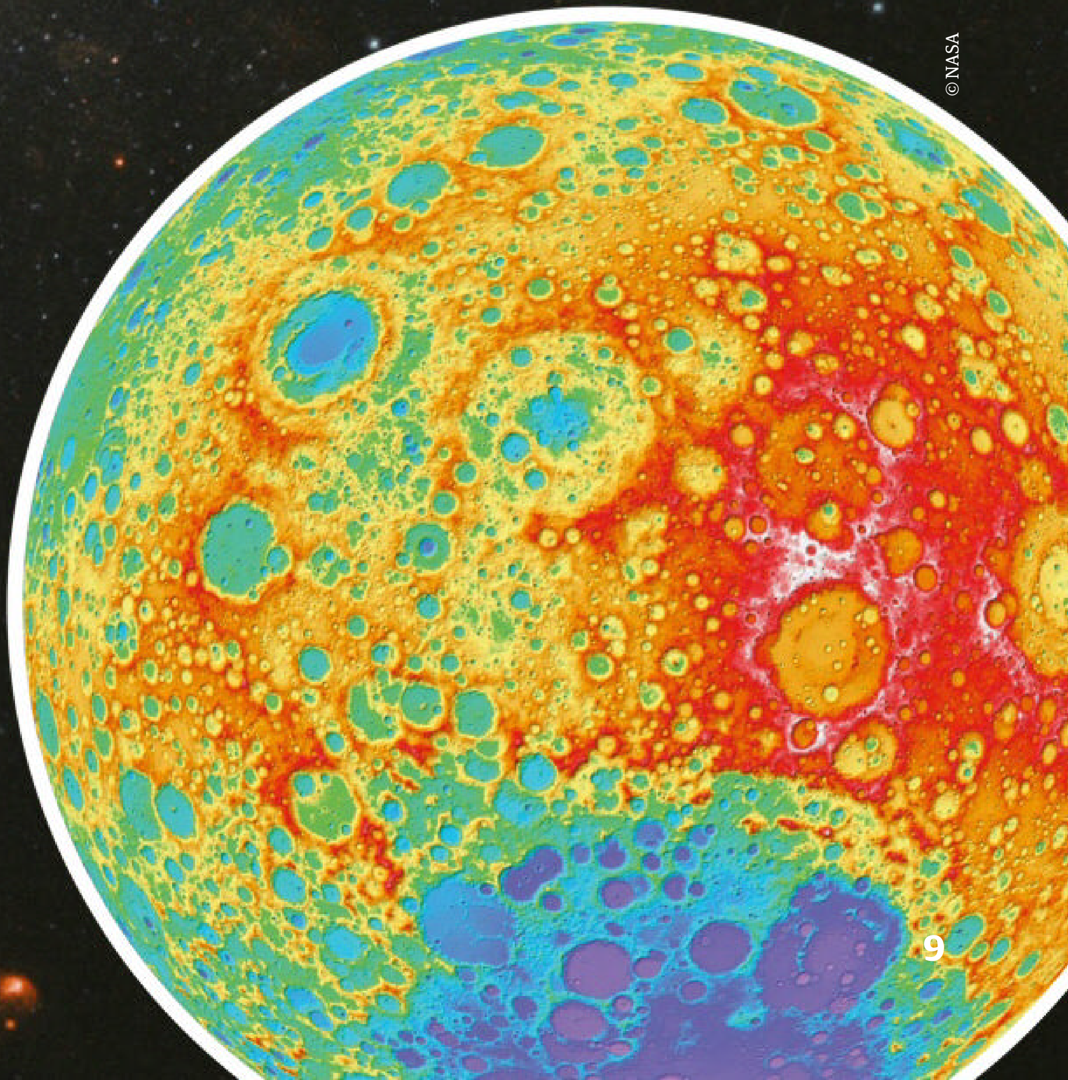


© NASA/ESA/Hubble

Springtime in the cosmos

'Stellar flowers' are blossoming in the cosmic field as irregular dwarf galaxy NGC 1156 settles into its own springtime. Instead of having petals bloom, these wonderful bubbles are pockets of gas illuminated by stars born within them.

Although it makes a pretty picture it's also a test bed for conducting real science. After collecting many images of NGC 1156, astronomers realised that some of these bubbles rotate in the opposite direction to the rest of the galaxy. This unusual observation indicates that this galaxy has encountered another structure in its past and was reshaped by the gravity of the passing galactic neighbour.



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The Moon's colourful side

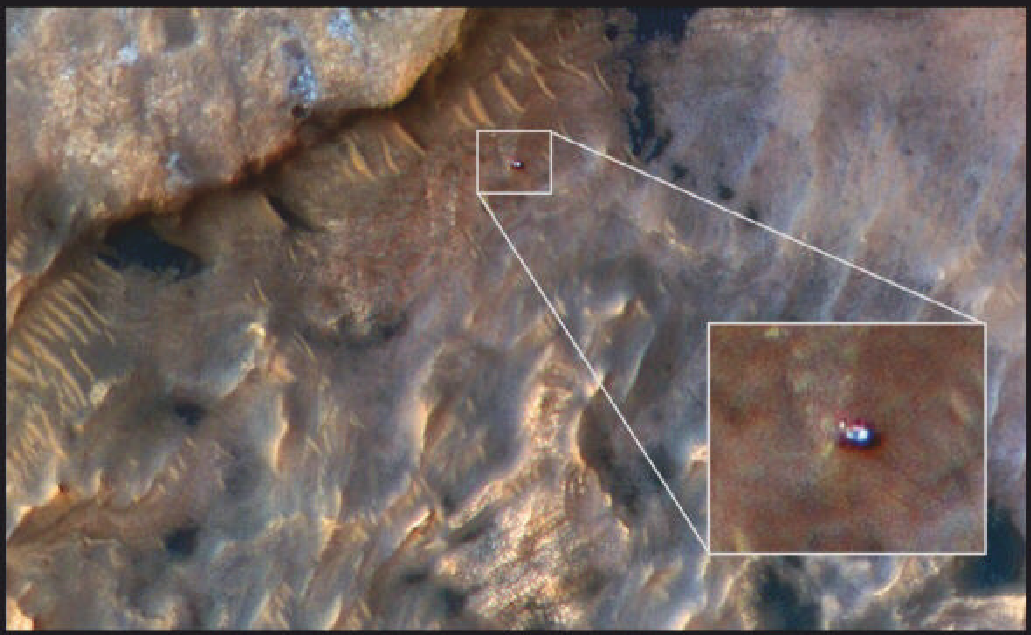
With so much focus on the Moon over the past few months, it's refreshing to see another side to it. Here is a colourful topographic map of the lunar surface taken by NASA's Lunar Reconnaissance Orbiter (LRO), which reveals areas of various elevation. Shown in red, the highest elevation on the Moon is around eight kilometres (five miles) while lower peaks descend to yellow, then green, then blue and finally to purple, showing a decline to roughly minus eight kilometres (minus five miles).

© ESA

Calibration is key

The European Space Agency and the Russian space agency, Roscosmos, will launch their first-ever Martian rover next year as part of the ExoMars 2020 mission. Recently engineers have been preparing its instruments to make sure it 'knows' what it is looking at.

This picture here shows the Close-Up Imager (CLUPI), which will do as its names suggests – take close-up, high-resolution colour images of Martian rocks and soil. Sitting in front of it is its calibration sample. That is an actual piece of Mars that was ejected from the Red Planet millions, or maybe even billions, of years ago and made its way through the Earth's atmosphere to the country of Oman in 2001.



Curiosity from above

While NASA's Curiosity rover performs its close inspection of Mars, searching for signs of life and navigating the alien terrain, some spacecraft are able to look down on it from Martian orbit – as shown in this image taken by NASA's Mars Reconnaissance Orbiter's (MRO) High Resolution Imaging Science Experiment (HiRISE) camera.

The Curiosity rover has been shot here as a blue flash in the 'Woodland Bay' on the side of Mouth Sharp in the Gale Crater. Just at the top of the picture is the Vera Rubin Ridge, a region Curiosity has already visited.

© NASA/JPL-Caltech

Mars 2020 gets its legs and wheels

Here are the hardworking engineers at NASA's Jet Propulsion Laboratory in Pasadena, California, putting on the Mars 2020 rover's legs and wheels – arguably the most important part of a rover – otherwise referred to as the mobility suspension.

After the engineers tick that part off the list, they will next move onto installing the robotic arm, the SuperCam instrument and the Sample Caching System. This system includes 17 separate motors that will collect samples of Martian rock and soil that will be returned to Earth by a future mission.

©NASA/JPL-Caltech

NASA shakes up human space exploration leadership

Words by **Mara Johnson-Groh**

In a move that took most people in the space industry by surprise, NASA has reassigned two top officials in its exploration programme, including Bill Gerstenmaier, the longtime head of NASA's human spaceflight programmes. In a memo to NASA employees issued late 10 July, NASA administrator Jim Bridenstine said Gerstenmaier, associate administrator for human exploration and operations, had been reassigned to serve as a special assistant to NASA deputy administrator Jim Morhard. Bridenstine said that Ken Bowersox, a former astronaut who rejoined the agency earlier this year as Gerstenmaier's deputy, would take over as acting associate administrator.

Also reassigned was Bill Hill, who had been deputy associate administrator for exploration systems development, who will now be a special advisor to associate administrator Steve Jurczyk. Tom Whitmeyer will take over as deputy associate administrator on an acting basis.

Bridenstine's memo gave few specifics about why he was replacing Gerstenmaier and Hill. "As you know, NASA has been given a bold challenge to put the first woman and the next man on the Moon by 2024, with a focus on the ultimate goal of sending humans to Mars," he wrote. "In an effort to meet this challenge, I have decided to make leadership changes to the Human Exploration and Operations (HEO) Mission Directorate."

Moving personnel into 'special advisor' positions is typically considered a demotion for those who cannot be terminated outright. Those positions have few, if any, responsibilities, and those reassigned as special advisors usually leave the agency shortly thereafter.

The timing of the reassignments took most within and outside the agency by surprise. Bridenstine, speaking at the Future Space 2019 conference on 10 July, offered no hints of an impending shake-up, offering a general overview of NASA's exploration plans, including development of the Lunar Gateway.

Gerstenmaier also provided no signs of a reassignment when he testified 10 July before the House Science Committee's space subcommittee on commercial activities on the International Space Station. His testimony, and the overall hearing, focused on the low -Earth orbit commercialisation strategy that NASA announced in June.

Some have speculated that the reassignments are the result of displeasure by agency leadership – and possibly the White House – at the pace of development of the Artemis lunar program and its key elements, the Space Launch System and the Orion spacecraft.

"The president has directed NASA and administrator Jim Bridenstine to accomplish this goal by any means necessary," Vice President Mike Pence said in a March speech where he announced the 2024 lunar landing goal. "You must consider every available option and platform to meet our goals, including industry, government and the entire American space enterprise."

NASA has big plans to return to the Moon by 2024

© NASA

Hubble peers back in time to the furthest galaxies

© NASA/ESA

Words by **Passant Rabie**

New Hubble constant stokes mystery of universe's expansion

Scientists have come up with a new measurement for the expansion rate of the universe, leading to questions regarding the discrepancies between current observations and the model of the universe that astronomers have relied on for years. New observations made using the Hubble Space Telescope indicate that the universe is expanding at the rate of just under 70 kilometres (43 miles) per second per megaparsec, a distance equivalent to 3.26 million light years.

This expansion rate is slightly slower than previous measurements taken by Hubble and the European Space Agency's (ESA) Gaia satellite, which indicated that the universe is expanding at 73.5 kilometres (45.6 miles) per second per megaparsec. Another earlier measurement by the ESA's Planck satellite has shown that the universe is expanding at a slightly slower rate of 67.4 kilometres (41.6 miles) per second per megaparsec.

To measure the universe's expansion rate - the Hubble constant - astronomers typically look at stars and galaxies to see how fast they seem to be moving apart. The Planck measurement, however, is based on the cosmic microwave background. By looking for 'echoes' of the Big Bang, Planck provided clues about what the universe looked like in its infancy and enabled predictions of how the universe would have evolved to reach its current expansion rate.

"This new evidence suggests that the jury is still out on whether there is an immediate and compelling reason to believe that there is something fundamentally flawed in our current model of the universe," Wendy Freedman, a professor of cosmology at the University of Chicago, said.

Protests continue against construction of Hawaiian telescope

Words by **Doris Elin Salazar**

Hundreds of protesters, including native Hawaiian community members, their elders (kupuna) and others have been gathering on the road leading to the summit of Mauna Kea on Hawaii's Big Island to challenge the addition of another telescopic facility to the mountain that is sacred to many on the island.

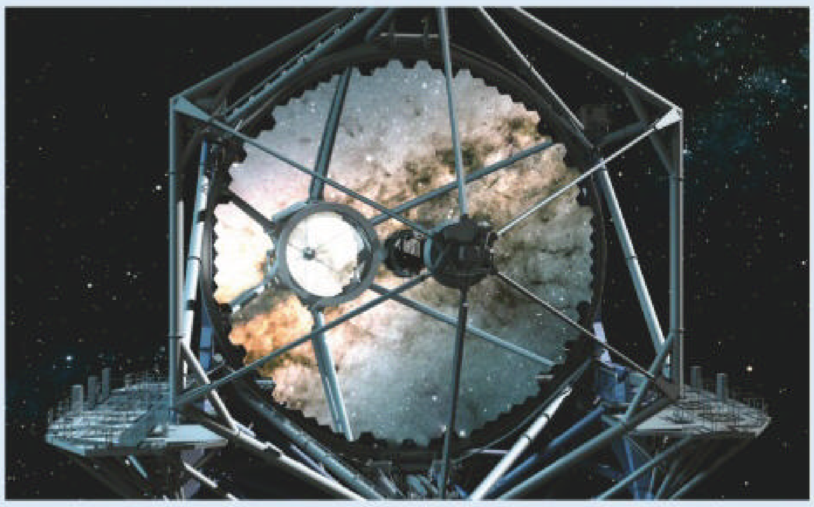
The group has been situated at the base of the mountain since 15 July, when construction gear was first scheduled to begin arriving for the $1.4 billion Thirty Meter Telescope (TMT) project, according to the Associated Press. There were about 500 people gathered at Mauna Kea on Monday, according to the *Honolulu Star-Advertiser.*

Unarmed National Guard units have been on the scene since Monday; arrests began on the morning of 17 July morning and continued in front of a crowd that had grown to 2,000 people, according to the AP. The AP added that astronomers took active telescopes on the mountain offline on 16 July because of inconsistent staff access to the site.

Mauna Kea, which remains a place of prayer to this day, is an inactive volcano that rises 4,205 metres (13,796 feet) above sea level. Its base lies under the Pacific Ocean, and if measured from bottom to top, Mauna Kea outshines Mount Everest as the tallest mountain on the planet.

The debate about the TMT began when project officials selected Mauna Kea as its site in 2009. Telescope officials say the TMT is valuable to science because the next-generation facility has the capacity to peer deeper into space and farther back in time than existing instrumentation, taking imagery several-times sharper than what the Hubble Space Telescope can see.

An artist's impression of the Thirty Meter Telescope (TMT)



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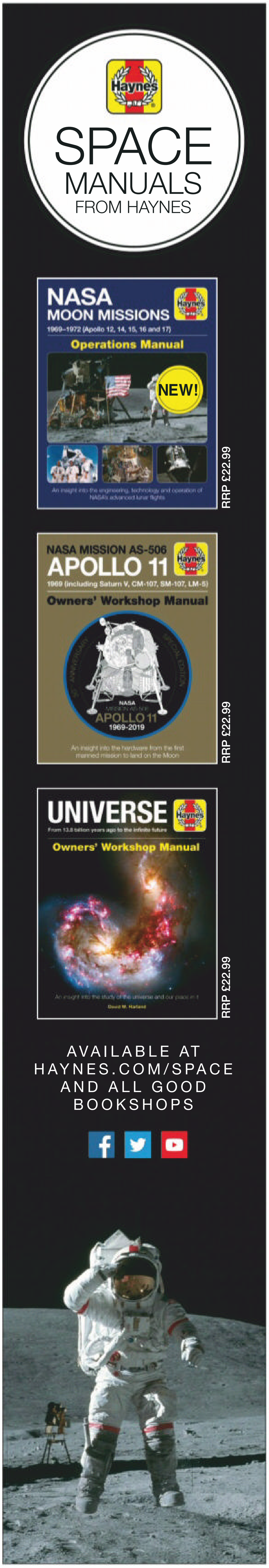

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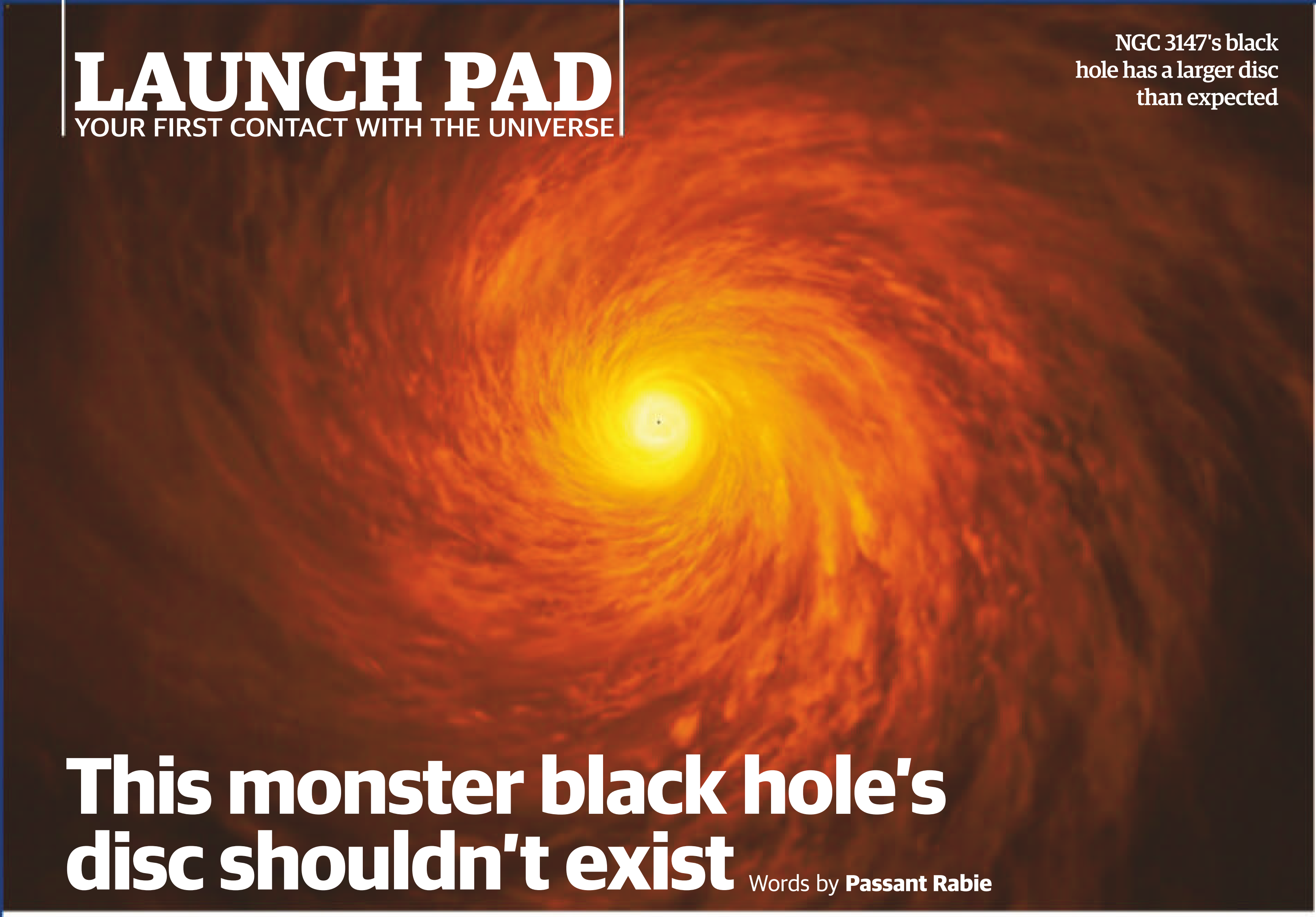

NGC 3147's black hole has a larger disc than expected

© ESA

This monster black hole's disc shouldn't exist

Words by **Passant Rabie**

Astronomers have discovered a thin disc of material spiralling into a supermassive black hole in a very faint galaxy – an unexpected finding that may provide further clues to the dynamic processes surrounding black holes.

Using the Hubble Space Telescope, astronomers observed the black hole at the centre of the spiral galaxy NGC 3147, which is located around 130 million light years away in the Draco constellation. Black holes in low-luminosity galaxies like NGC 3147 usually lack sufficient material captured by the galaxy's gravity to feed from, and are therefore considered 'starving'.

The researchers were surprised to find a thin disc encircling the black hole at the centre of this galaxy because the disc looks similar to the kinds of accretion discs that typically encircle black holes found in extremely active, and much brighter galaxies.

"The type of disc we see is a scaled-down quasar [a luminous galactic nucleus] that we did not expect to exist," Stefano Bianchi, an astrophysics professor at Roma Tre University in Italy and lead author of the study, said in a statement. "It's the same type of disc we see in objects that are 1,000 or even 100,000-times more luminous."

The disc is so deeply embedded in the black hole's gravitational field that the light being emitted from the gas disc is altered by the intense gravitational pull. Hubble measured the disc spinning around the black hole at more than ten per cent of the speed of light, causing it to brighten as it moves towards Earth and dim when it moves away from our planet. Scientists can use these observations to test Albert Einstein's theories of relativity.

"The predictions of current models for very faint active galaxies clearly failed," Bianchi said.

Astronaut cancer deaths not caused by space radiation

Words by **Rachael Rettner**

Outer space is a notoriously harsh environment, exposing astronauts to high levels of radiation. And radiation exposure can increase cancer and heart disease rates in earthbound humans. But a new study has some good news: space radiation doesn't seem to increase astronauts' risk of death from cancer or heart disease, at least not at the doses they experienced during historical missions. Still, longer missions - such as a mission to Mars - will likely come with much greater radiation doses that could pose larger health risks.

Space travel exposes the body to higher levels of ionising radiation than those typically experienced on Earth. At high doses that radiation has been tied not just to cancer and heart disease, but to a host of other health problems.

The new study analysed information from 418 space travellers, including 301 NASA astronauts, who had travelled to space at least once since 1959.

During this time, 89 of the participants died. Among the 53 NASA astronauts who died, 30 per cent died from cancer and 15 per cent from heart disease, while among the 36 Russian or Soviet cosmonauts, 50 per cent died from heart disease and 28 per cent from cancer.

"If ionising radiation is impacting the risk of death due to cancer and cardiovascular disease, the effect is not dramatic," the authors wrote in their study, published 4 July in the journal *Scientific Reports*.

Still, the study cannot determine whether longer missions would pose different risks. "It is important to note that future missions of deep-space exploration will likely offer much greater doses of space radiation than have historical doses, which will lead to a different risk profile for future astronauts and cosmonauts," the authors said.

© NASA

Exomoons have a new name

© NASA/ESA

Runaway exomoons now known as ploonets

Words by **Mindy Weisberger**

Scientists had previously proposed the endearing term 'moonmoons' to describe moons that may orbit other moons in distant systems. Now, another team of researchers has coined the melodious nickname 'ploonet' for moons of giant planets orbiting hot stars; under certain circumstances, these moons abandon those orbits, becoming satellites of the host star. The former moon is then 'unbound' and has an orbit like a planet's – ergo, a ploonet.

Ploonets have yet to be detected, but ploonets may produce light signatures that planet-hunting telescopes could identify, researchers reported in a new study.

For the study the scientists created computer models to test scenarios that might transform a planet-orbiting moon into a star-orbiting ploonet. The researchers found that if a moon is circling a type of exoplanet known as a 'hot Jupiter' – a massive gas giant close to a star – the gravitational tug of war between star and planet could be powerful enough to wrest the moon from its planetary orbit and send the object circling around the star instead.

However, most ploonets would likely be relatively short-lived. The majority of the objects disappeared within a million years and never became planets; instead, they disintegrated during collisions with their former host planets, were gobbled up by stars in acts of 'planetary cannibalism' or were ejected from orbit.

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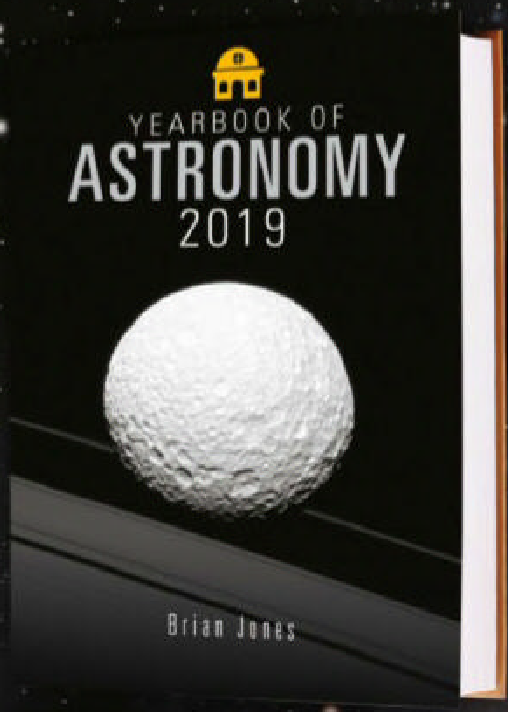

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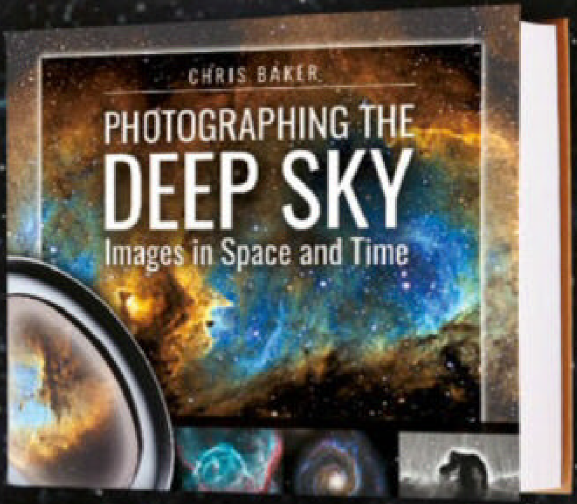

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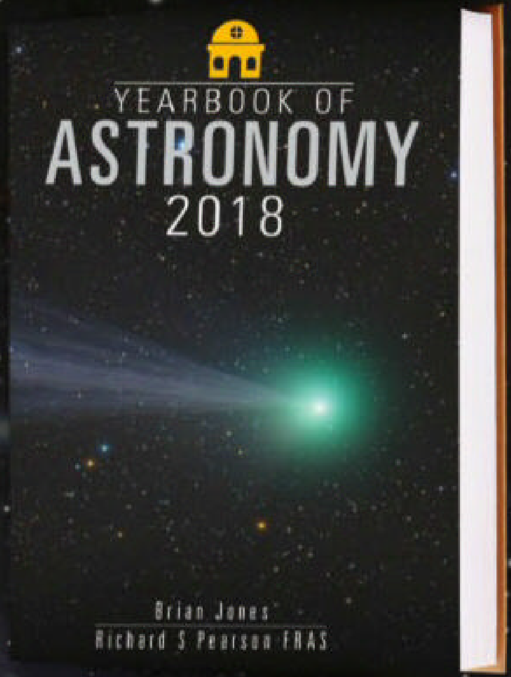

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MISSION TO

CATCH A COMET

Comet Interceptor will make history by visiting a distant 'space snowball' - or an interstellar object

Reported by Jonathan O'Callaghan

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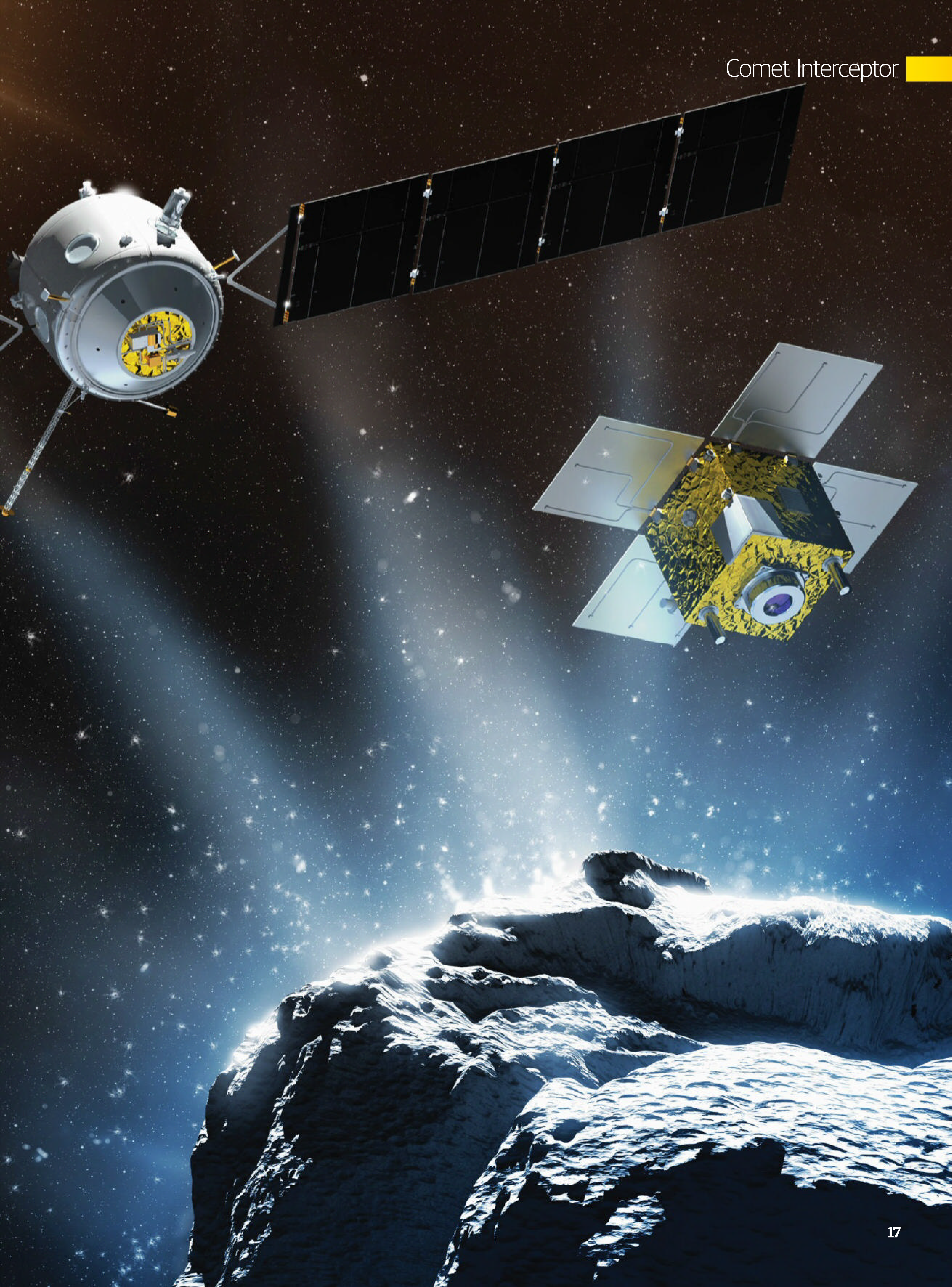


Every so often in our Solar System, a comet swings in from the outer reaches and makes a brief visit to the inner portion of the system before heading out again - either on a long sweeping orbit, or never to be seen again. Such comets, known as long-period comets, are of great interest to scientists, but we've only ever seen them from afar. What if we could see one up close?

That's the idea behind a new mission called Comet Interceptor, which in June 2019 was selected by the European Space Agency (ESA) for further development, with a potential launch planned in 2028. The mission will be unprecedented, launching with no particular target in mind, but instead waiting in space for a suitable comet to approach from the Oort Cloud, the vast array of trillions of comets thought to surround our Solar System. If one gets nudged from its orbit and does approach - and it's hoped it will - the spacecraft will race off and fly past, returning images and data to Earth in the process.

"It's a unique target," says Dr Colin Snodgrass from the University of Edinburgh in the UK, the deputy lead on the Comet Interceptor mission proposal. "Going to a dynamically new comet from the Oort Cloud is something we've never done before. And it's something we couldn't normally conceive of doing, because these comets are discovered a couple of months or years before they come past, and that's too short to launch a mission. So it's unique because we're able to wait in space and intercept this new target."

Comet Interceptor is known as an F-class mission, or 'fast' mission. This isn't in reference to its plans in space, but rather its development time. Having been selected, the team will now plan to have the mission ready to launch in eight years. The mission will have a mass of less than 1,000 kilograms and will head to space in 2028 as a secondary mission on launch of the Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) telescope, designed to hunt for planets beyond the Solar System.

The two missions will be sent 1.5 million kilometres (1 million miles) from Earth beyond the Moon, to a location known as Lagrange point 2 (L2). Here the gravity of the Moon and Earth essentially cancel out, allowing spacecraft to remain in one position in space without expending too much fuel. While ARIEL will be deployed here permanently to look for exoplanets, Comet Interceptor will be ready and waiting for its mission to begin.

In the build-up to the mission, and after its launch if necessary, the team will be keeping a very close eye on the skies to look for potential targets to visit. They will make use of vast surveys of the sky like the Large Synoptic Survey Telescope (LSST) in Chile, which will switch on in 2020, to look for any long-period comets entering the Solar System. The team will be on the hunt for a comet that approaches roughly to Earth's orbital plane, which would make an interception possible.

"It has to get close to Earth's orbit," says Snodgrass. "It doesn't necessarily have to get close to Earth, but it has to come to about one

Right (clockwise): In 2014 Europe's last comet mission, Rosetta, entered orbit around Comet 67P/Churyumov-Gerasimenko, ending in 2016

Comet 73P/Schwassmann-Wachmann 3, which has broken apart, is a backup target for Comet Interceptor

Comets may have brought water, and even life, to Earth early in its history

© ESA

Why study a comet?

What we can learn about these icy bodies as they make their way around the Sun

Water, water everywhere

Comets contain vast amounts of water-ice, both on their surface and underground. We think they may have been responsible for delivering water to Earth in its past, so studying them can tell us more about whether this is true or not.

Origins of life

It's also thought that comets may contain some of the key ingredients for life, such as amino acids. Again, like water, it's possible that these ingredients were brought to the young Earth by comets hitting our planet - perhaps giving rise to all life as we know it!

The giant planets

As comets are icy, they likely formed in the Solar System's outer reaches early in its history. This is the same location that some of our larger planets like Saturn and Neptune are thought to have formed, so by studying comets we can learn more about those worlds.

Why are they different?

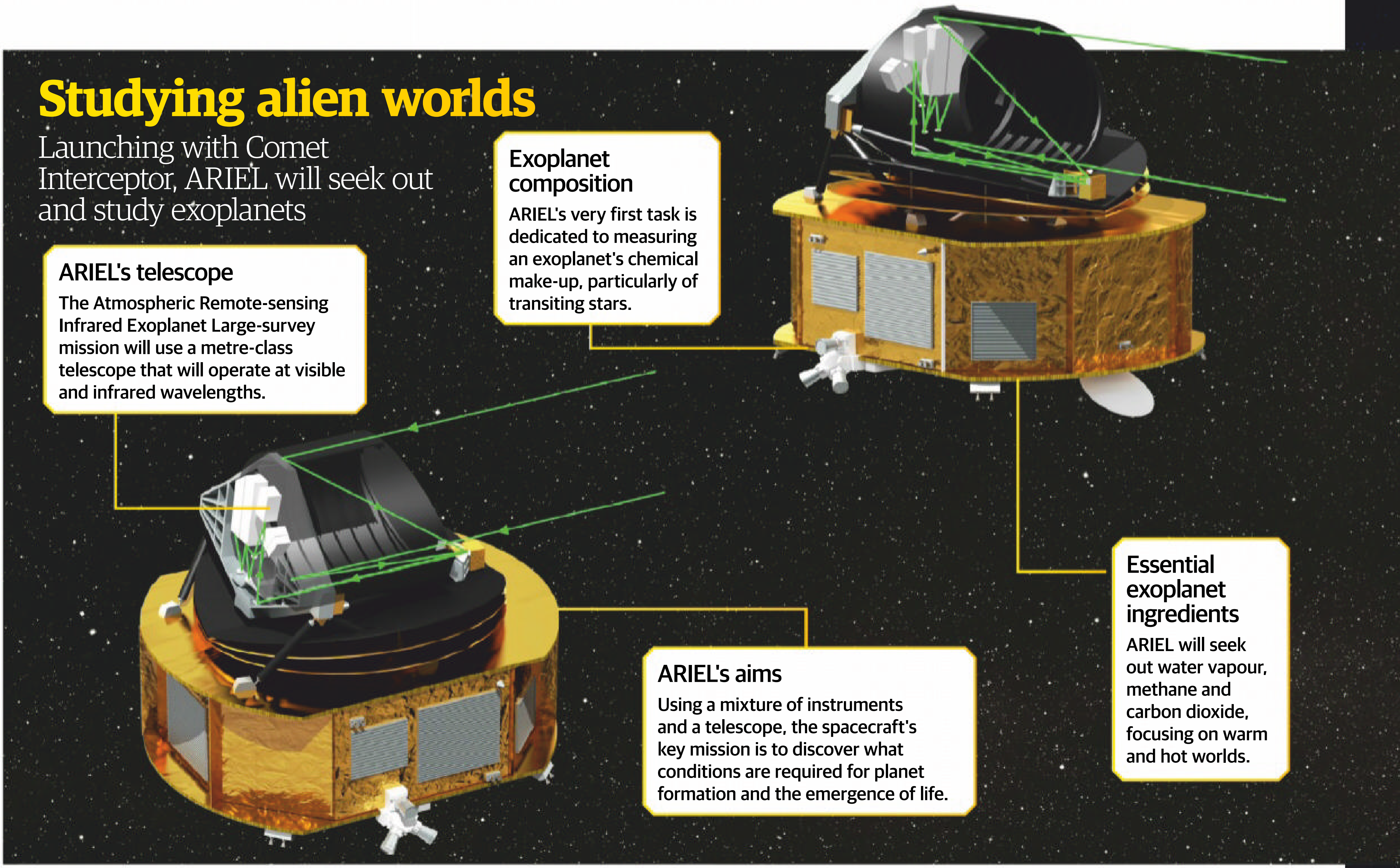
If all comets formed in the outer Solar System, you would expect them to be mostly the same. But we are rapidly finding that is not the case, with many comets having unique compositions and abundances of water. Finding out why is key to understanding the Solar System's evolution.

Could one hit Earth?

A comet is thought to have wiped out the dinosaurs 66 million years ago, but could such an event occur again? Finding comets can help us look for any that might be on a collision course with Earth - although so far, the coast is clear.

Science in action!

Comets are fascinating laboratories of science where we can see some amazing processes taking place. As they approach the Sun they form large tails that extend long behind them as they become more active. Studying them is quite simply scientifically interesting!



Studying alien worlds

Launching with Comet Interceptor, ARIEL will seek out and study exoplanets

ARIEL's telescope

The Atmospheric Remote-sensing Infrared Exoplanet Large-survey mission will use a metre-class telescope that will operate at visible and infrared wavelengths.

Exoplanet composition

ARIEL's very first task is dedicated to measuring an exoplanet's chemical make-up, particularly of transiting stars.

ARIEL's aims

Using a mixture of instruments and a telescope, the spacecraft's key mission is to discover what conditions are required for planet formation and the emergence of life.

Essential exoplanet ingredients

ARIEL will seek out water vapour, methane and carbon dioxide, focusing on warm and hot worlds.

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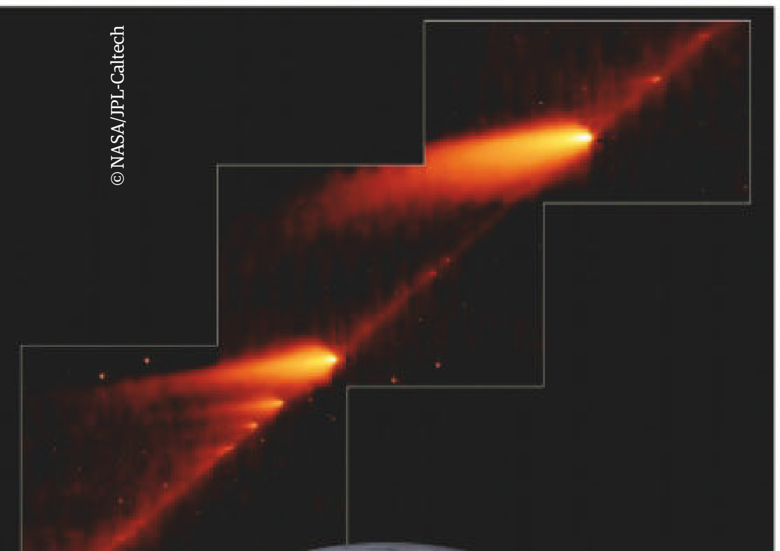

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> "Going to a dynamically new comet from the Oort Cloud is something we've never done before" **Dr Colin Snodgrass**

astronomical unit from the Sun, so the same distance that we are from the Sun. It could be around the other side of the Sun, although we would prefer it not to be because we want to be able to see it with Earth telescopes at the same time."

Once a target is spotted, Comet Interceptor will leave its position at L2 and make its way towards it, likely taking several months or years to reach the target. Once it reaches its target, however, it will not be able to enter orbit - like the ESA's Rosetta mission did around Comet 67P in 2014 - owing to the great velocities involved. Instead it will merely fly past, using a suite of instruments to study the comet as it does so - including mapping its surface, snapping images and measuring its composition.

The flyby will last just a matter of minutes, and the main spacecraft will likely fly past at a distance of about 1,000 kilometres (600 miles). This is because as the comet approaches the Sun for the first time, it is likely to become very active as its icy surface melts, throwing lots of debris into space into a coma that surrounds the comet's solid nucleus that could damage the spacecraft. However, to get a closer look Comet Interceptor will also carry with it two smaller spacecraft, which will be sent much closer to the comet.

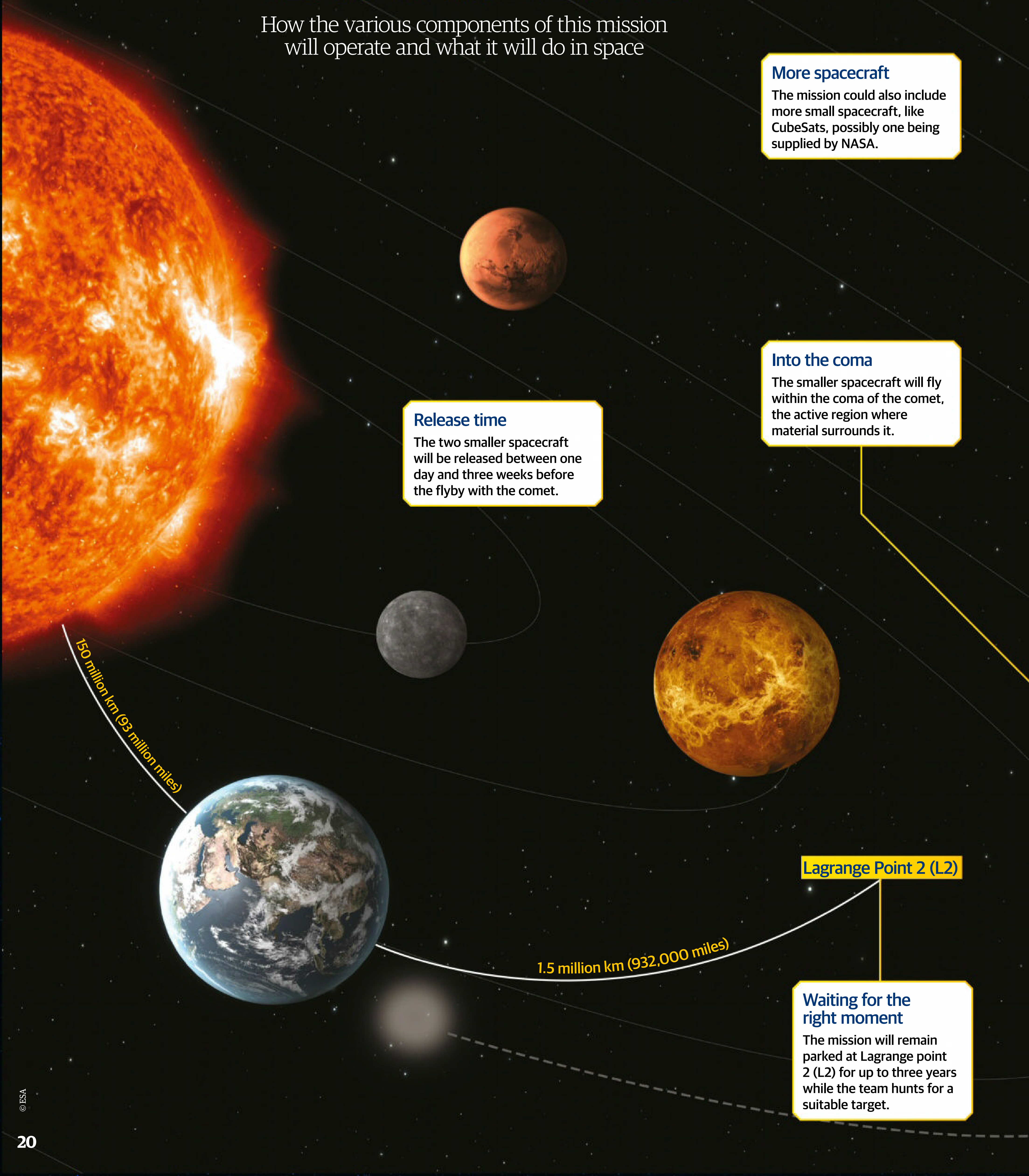
These will be equipped with shields at their front to deflect debris, and will be sent on much riskier excursions near the comet. They are more expendable than the main mothership, so the team will be more willing to take risks with them and send them closer to get better views and data. These smaller spacecraft have only been named B1 and B2 so far - and one of them will be built by the Japanese space agency, JAXA - while the larger spacecraft has only been named A for now.

Studying a long-period comet like this close-up for the first time has lots of interesting possibilities. While we have sent many spacecraft to comets before, including the aforementioned Rosetta mission, these have all been short-period comets. As these regularly orbit the Sun, their surfaces have been dramatically altered over time. Looking at a long-period comet, however, could give us a glimpse back into the dawn of the Solar System itself, and perhaps provide hints as to the origin of water and even life on Earth.

"Long-period comets are the ones that have orbits over 200 years," said research assistant Dr Ashley King, an expert in asteroids and comets from the Natural History Museum in London. "They tend to have really elliptical orbits, and these things come

Comet Interceptor: how it will work

How the various components of this mission will operate and what it will do in space


150 million km (93 million miles)
1.5 million km (932,000 miles)
Lagrange Point 2 (L2)

More spacecraft
The mission could also include more small spacecraft, like CubeSats, possibly one being supplied by NASA.

Into the coma
The smaller spacecraft will fly within the coma of the comet, the active region where material surrounds it.

Release time
The two smaller spacecraft will be released between one day and three weeks before the flyby with the comet.

Waiting for the right moment
The mission will remain parked at Lagrange point 2 (L2) for up to three years while the team hunts for a suitable target.

© ESA

Size of the spacecraft

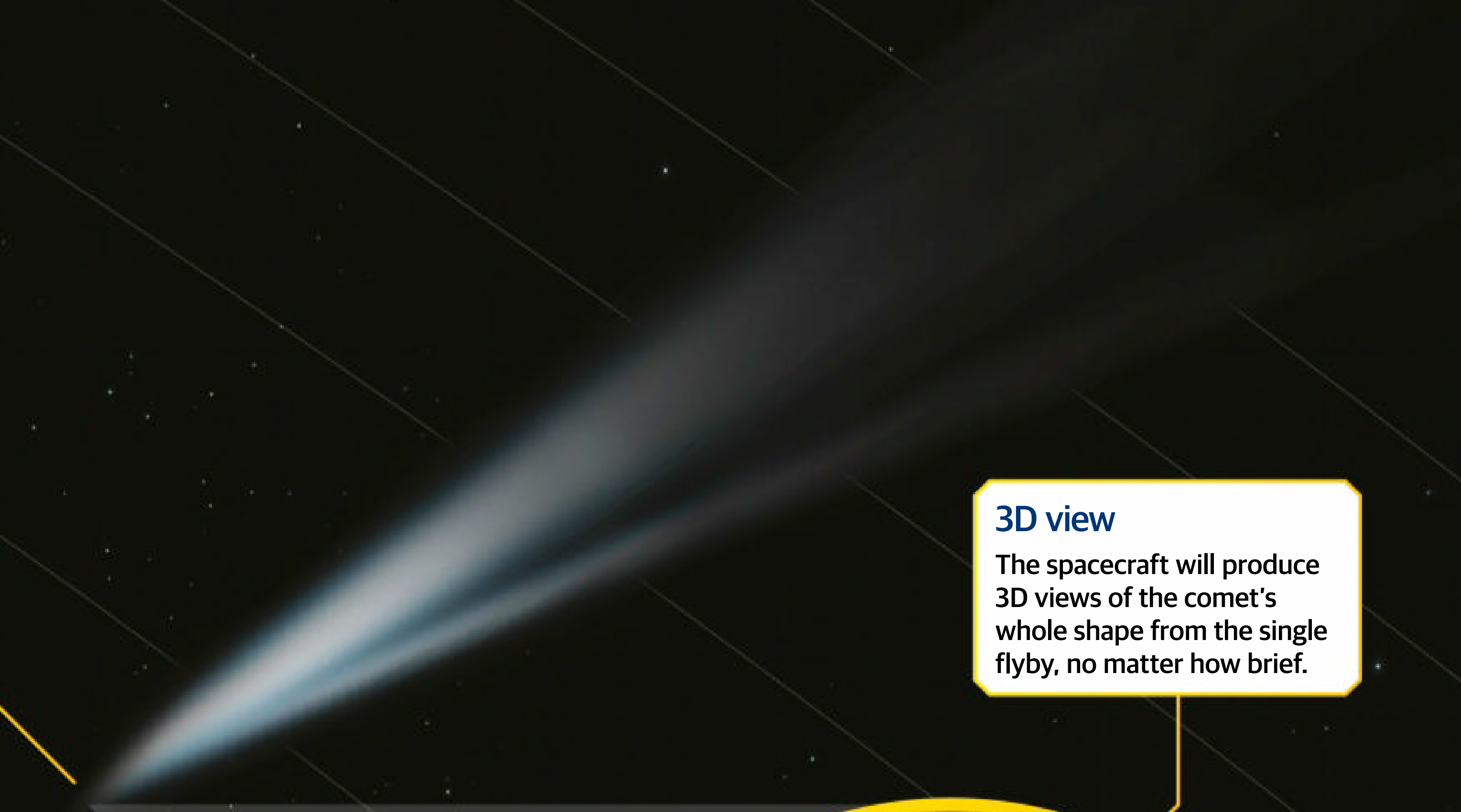
Comet Interceptor will weigh about 850 kilograms (1,900 pounds) in total, comprising all three spacecraft.

Plasma and atoms

The spacecraft will include instruments that will measure solar wind and plasma near and around the comet.

Three-in-one

The mission will comprise three spacecraft – one mothership to fly far from the comet, and two smaller spacecraft to fly closer.



3D view

The spacecraft will produce 3D views of the comet's whole shape from the single flyby, no matter how brief.

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Comet Interceptor by the numbers

€150 MILLION

Total cost of the mission in euros

2028

Proposed launch date for the mission

0.8 to 1.2

Distance in AU to the Sun the comet needs to approach to be reached by the mission

1,000km

Closest approach of the main spacecraft to the comet

70km/sec

Maximum likely flyby speed for the spacecraft at its target

10km/sec

Minimum likely flyby speed for the encounter

2033

Time by which the mission must be completed due to costs

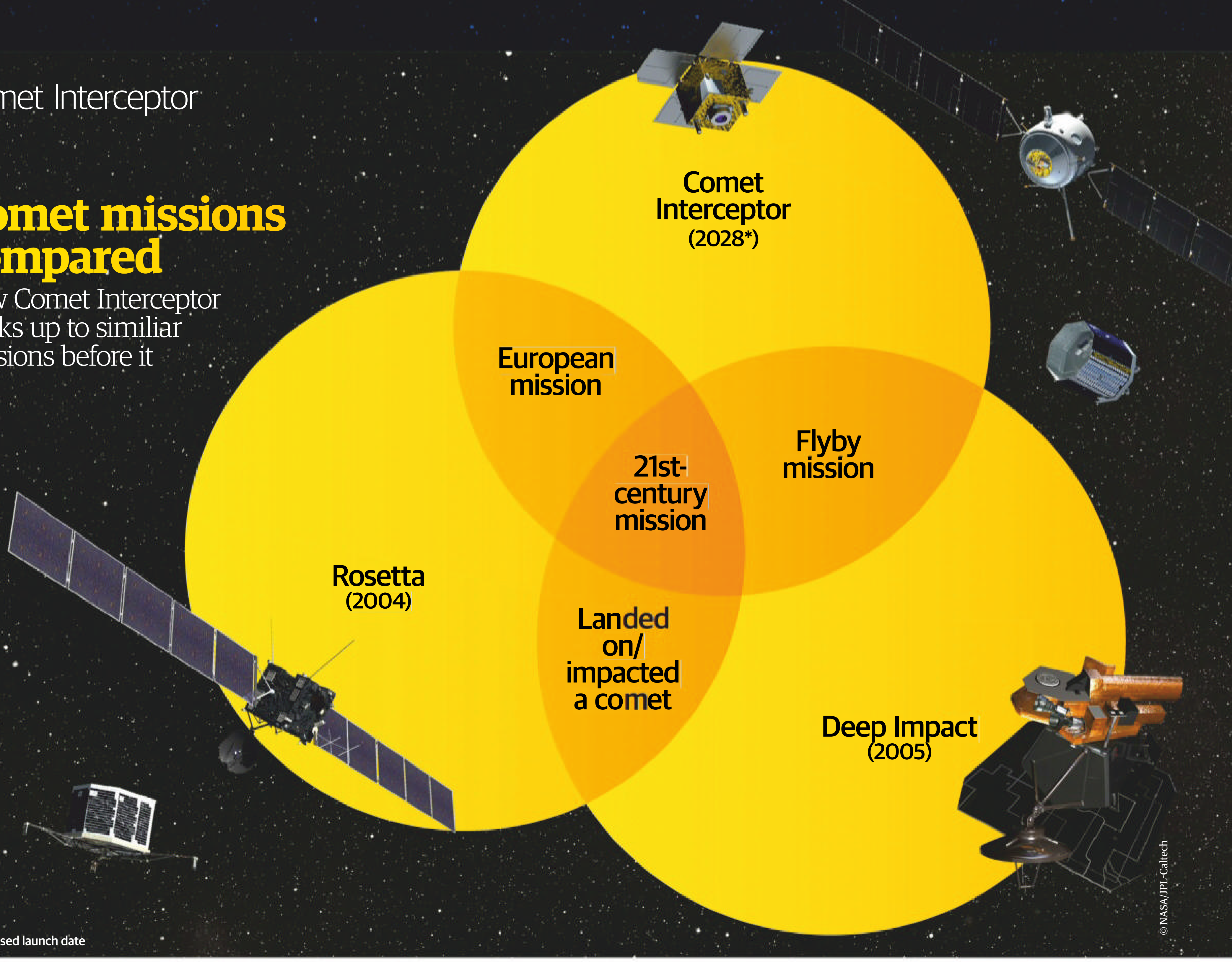
1

Number of interstellar objects found in our Solar System so far

© Illustration by Adrian Mann

Comet missions compared

How Comet Interceptor stacks up to similiar missions before it



*Proposed launch date

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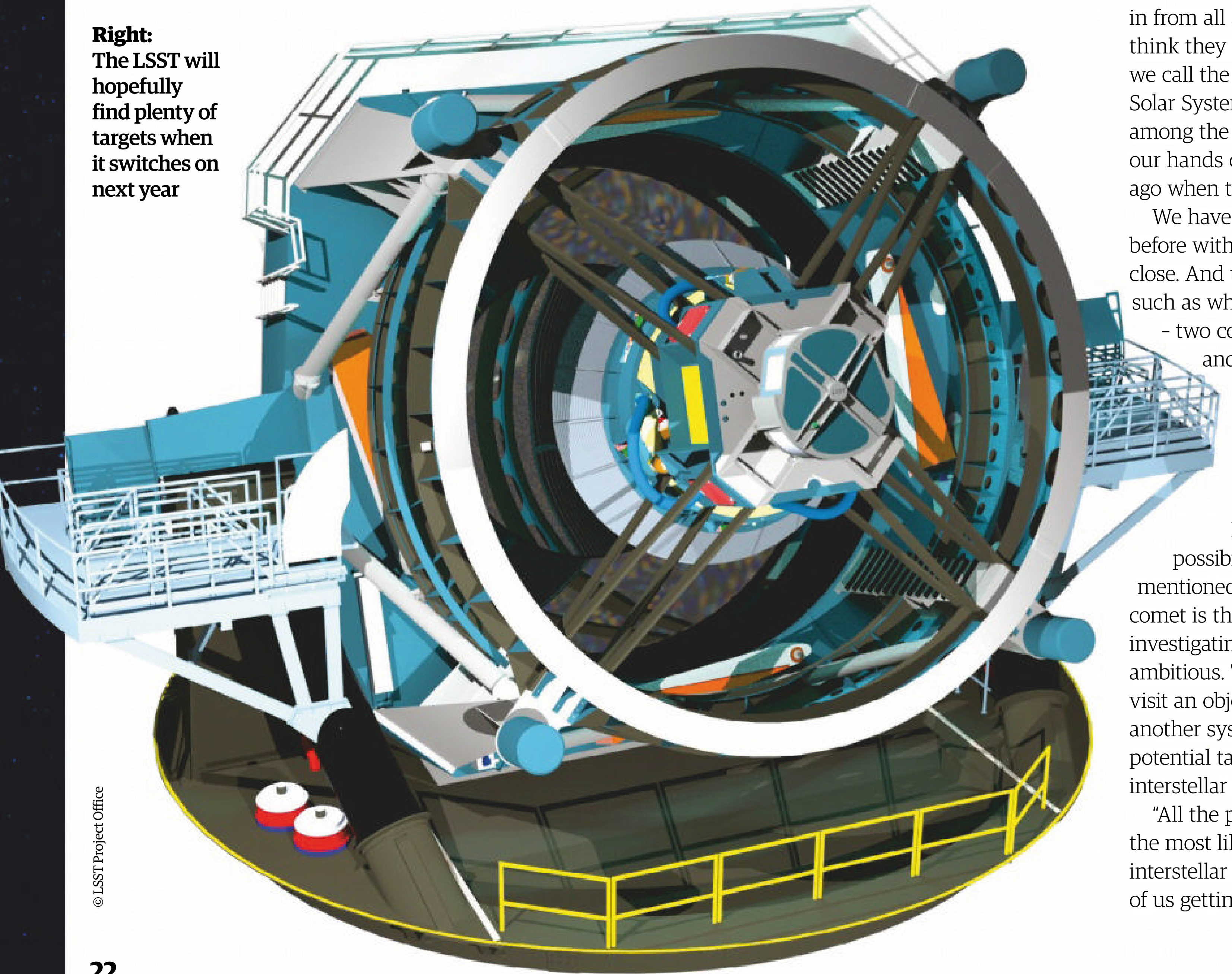
Right: The LSST will hopefully find plenty of targets when it switches on next year



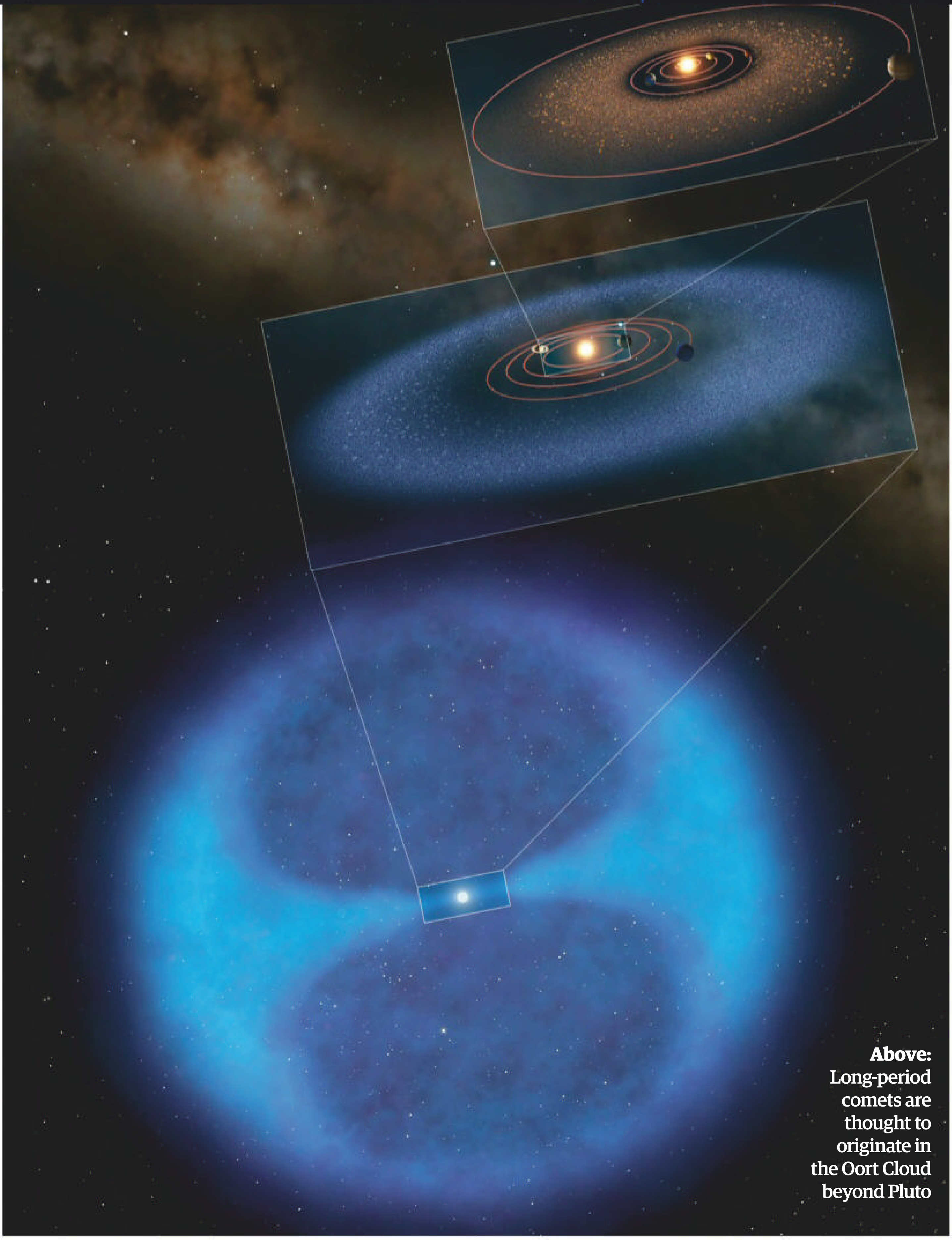
© LSST Project Office

in from all sorts of weird and wonderful angles. We think they come from this hypothetical area that we call the Oort Cloud, way out on the edge of the Solar System beyond Pluto. And these are probably among the most pristine material that we can get our hands on, stuff that was there 4.5 billion years ago when the Solar System formed."

We have been able to study long-period comets before with telescopes, but we've never seen one up close. And there are a lot of unanswered questions, such as whether they are mostly binary objects - two comets stuck together, like Comet 67P - and what their surfaces look like. Surveys like the LSST are expected to find thousands of comets every year, and some of these will be hoped to be long-period comets that Comet Interceptor could visit.

But there is another incredibly alluring possibility with this mission that we haven't mentioned yet. Because while a long-period comet is the main target, the team will also be investigating the possibility of something far more ambitious. They will see if it might be possible to visit an object not from our Solar System, but from another system entirely. Comet Interceptor's other potential target is not a long-period comet, but an interstellar object from afar.

"All the planning is for a comet, because that's the most likely case," Snodgrass explains. "The interstellar object is a possibility, but the chances of us getting one are pretty slim. With the comet



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Above: Long-period comets are thought to originate in the Oort Cloud beyond Pluto

> "It would be really amazing to get a feel for other types of materials that we find out there in the universe" **Dr Ashley King**

we'll have a few years warning – we'll see it coming. Whereas if [an interstellar object] behaved like an asteroid and it doesn't have activity, you wouldn't see it until it's really close to you. Then we won't have a lot of warning, and the chances we can intercept it are slim. If we did find one with enough time, I think there would be a very strong push to do so because scientifically that would be an amazing opportunity."

That might sound far-fetched, but it's very possible. In October 2017 we detected an interstellar object inside our Solar System for the first time. Dubbed 'Oumuamua, it's thought this object – which may have been either an asteroid or a comet – had been ejected by a star from another planetary system and had made the long trek across interstellar space to our own Solar System. It visited only briefly, however, and is now too far for us to visit. But it came close to our Sun long enough for us to study it with telescopes.

It's hoped that at any given moment there might be at least one interstellar object in our Solar System. Finding them is difficult because they can be incredibly dim and move very quickly. But if one can be found while Comet Interceptor is waiting at L2, then the mission may not go to a long-period comet at all. It may instead attempt to intercept an interstellar comet, also a historical first and, arguably, a greater cause.

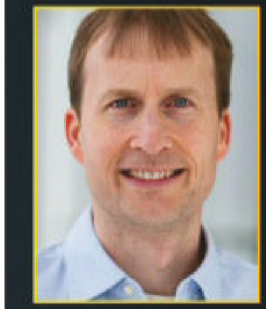
"It probably has to be [the most alluring possibility]," said Dr Nicholas Attree, a research fellow and comet expert from the University of Stirling in Scotland. "If you had a chance to go for an interstellar object it would be really amazing and

What's going to be the biggest breakthrough?

Members of the Comet Interceptor team discuss their biggest hopes for the mission

"It will be like getting to look at a time capsule"

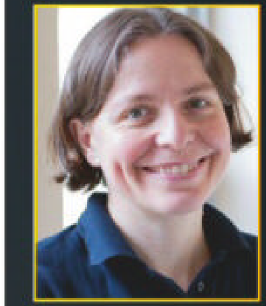
Matthew Knight, University of Maryland and Consortium Member



"To me, the most important aspect of the mission will be getting detailed observations of a 'new' comet nucleus for the first time. All comets humanity has visited have been in the inner Solar System for many years, but Comet Interceptor will give the first glimpse of what a comet looks like before it has been extensively heated by the Sun. It will be like getting to look at a time capsule from our Solar System's distant past."

"It consists of three spacecraft, a first among cometary missions"

Marina Galand, Imperial College of Physics, lead on the magnetometer instrument on spacecraft B2



"One exciting originality of Comet Interceptor is that it consists of three spacecraft, a first among cometary missions. This enables multipoint measurements, which are essential to build a 3D picture of the gas, dusty plasma and magnetic field environment around an active cometary nucleus. This will revolutionise our view of the interaction of a comet with the space environment it encounters and offer critically new insights on how energy, momentum and mass are transferred between the comet and its environment."

completely unprecedented. In some small way I'd be kind of sad that we didn't go to a comet, but it would be a unique opportunity to do that."

King agrees that while it would be a tough decision, the possibility of visiting an interstellar object would be too tempting to pass up. "I think I would take an interstellar object," he said. "It would be really amazing to get a feel for other types of materials that we find out there in the universe, and see how those materials compare to other stuff in our own Solar System. It would be a new venture."

Finding such a target will be no easy feat. The team will be forced to make a tricky decision while waiting at L2 - should they go for the first target they see, or wait for the possibility of an even better object in the future? That will be decided in discussions to take place over the next few years, after the design of the mission has been refined.

The spacecraft will have funding to remain at L2 for three years. If in that time the team does not find a suitable target, either a long-period comet or an interstellar object, then they do have back-up objects to visit, such as a short-period comet called 73P/Schwassmann-Wachmann 3. While this would be less interesting, it is thought to be a comet that has broken apart, possibly revealing its core. So studying it, while slightly disappointing, would still provide a fascinating opportunity for unprecedented science.

Whatever happens, Comet Interceptor is set to be a mission like no other. It is the first time a space mission will have been launched with no specific target in mind, and it will explore an object never seen before too. Before the spacecraft even launches, however, surveys like the LSST are expected to throw up some potential targets, possibly even including some interstellar objects. It could even be that an optimal target is selected before Comet Interceptor launches. If not, it will wait patiently before heading out for its brief but historic encounter with an unseen world.

"We've done lots of simulations, and we're pretty confident that we will have targets we can reach," says Snodgrass. "If we find out they're plentiful, we can wait for a really good one. Whereas if these things only come along once every few years, then we'll go for the first one that we can."

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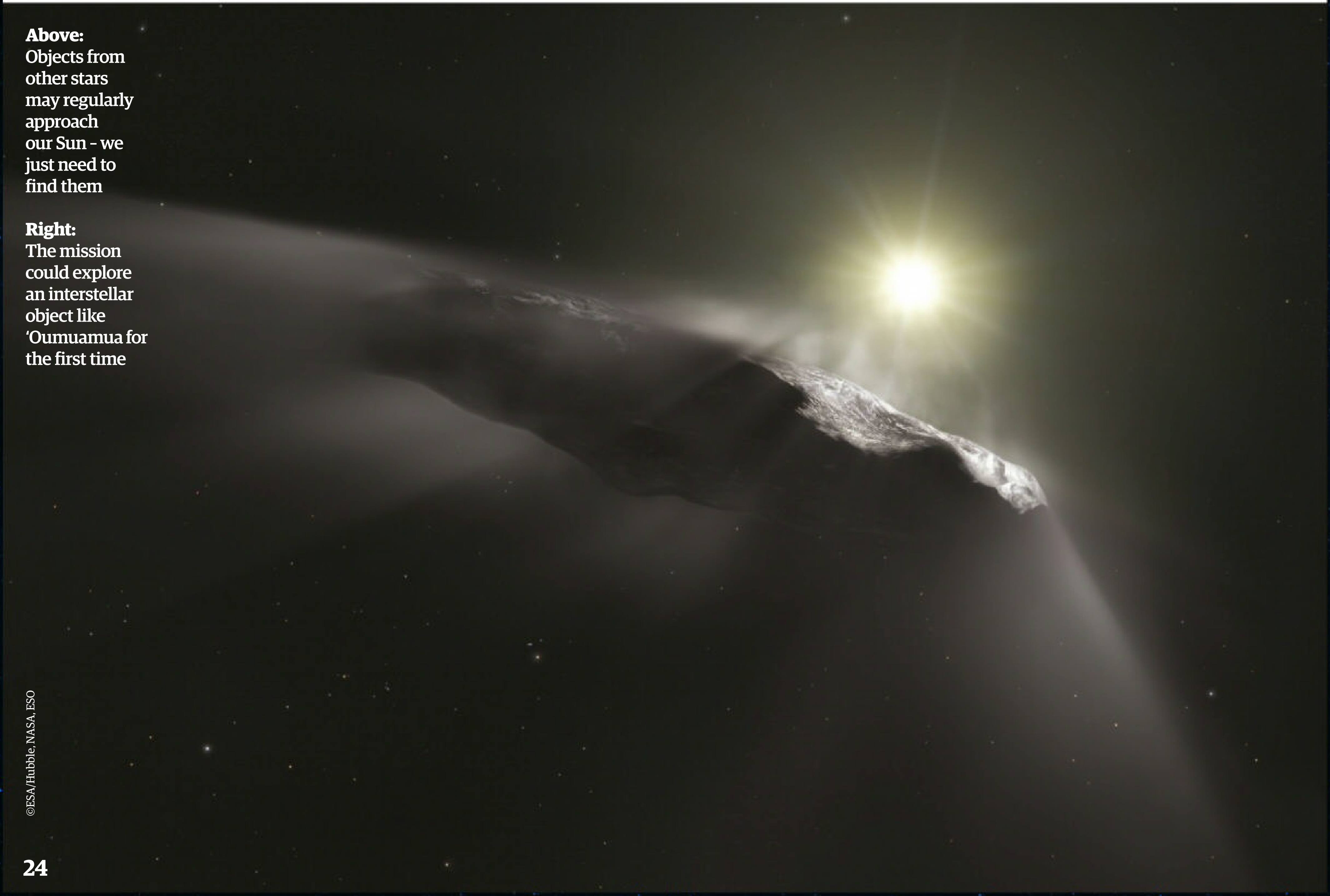

Above: Objects from other stars may regularly approach our Sun - we just need to find them

Right: The mission could explore an interstellar object like 'Oumuamua for the first time

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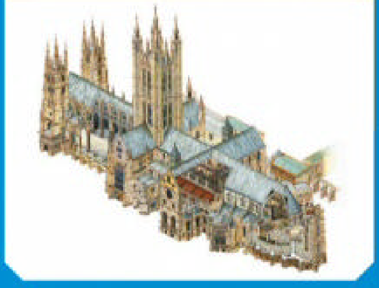

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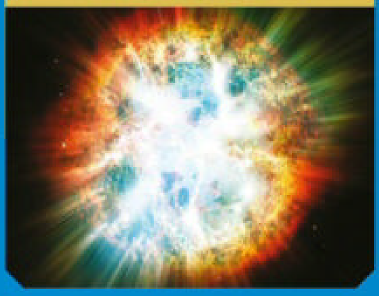

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REAPING THE REWARDS OF THE APOLLO PROGRAM

Much has come from the manned lunar missions, but it's important to look to the future. The UK Space Agency's Libby Jackson and the Open University's Dr Mahesh Anand reveal what's next in shooting for the Moon

Interviewed by Lee Cavendish

© NASA

Above: The South Pole-Aitken basin is a potential future exploration site

Left: Four days after launching from Earth, the Apollo 11 crew made it to the Moon

Below: Lunar meteorites tell a story of the Moon's evolution

You're sudying some of the rocks collected from the Apollo missions, how's that going?

MA: Only yesterday we were looking at those same rocks that Neil [Armstrong] and Buzz [Aldrin] were collecting in this [*8 Days: To the Moon and Back*] documentary. I study rocks from all the Apollo missions and to me, I mean, even right now as I speak, I've got hairs rising on my back because I'm just so privileged to be given access to these precious samples, which NASA calls 'the gift that keeps on giving'.

50 years on, over 380 kilograms of Moon rock and soil that were collected, more than half of it is still actually curated very well.

What discoveries have come from studying the samples?

MA: In the last ten years so many new discoveries have come about, and many of them because of having access to these Apollo samples. Some of the work that we have done at the Open University, for example, has been looking for water in these Moon rocks, and that has been a game-changer. In fact, that is one of the reasons why our space agency, and the rest of the world, is actually wanting to return to the Moon. With this new knowledge to do, of course more science, but also for various other reasons and to prepare themselves to go further beyond them in the not-so-distant future.

How soon are we going to go back to the Moon?

LJ: It's happening now. We've got instruments that are being built at the Open University. UK companies are going to land on the Moon in a robotic mission in the coming years. If I do my job properly, by the end of this year we'll see the UK and the European Space Agency (ESA) commit to be part of the Lunar Gateway. This is going to be a tiny space station, not the size of the International Space Station, that's going to be built near the Moon in the next few years. There are already parts being built.

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INTERVIEW BIO

Libby Jackson

Jackson is the human exploration manager at the United Kingdom (UK) Space Agency. She originally studied physics at Imperial College London, then astronautics and space engineering at Cranfield University, both in the UK, before going on to work with the European Space Agency for seven years, where she was a mission controller. She was the flight director for the International Space Station Columbus section. She also has a book out called *A Galaxy of Her Own: Amazing Stories of Woman in Space*.

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INTERVIEW BIO

Dr Mahesh Anand

Anand is a reader in planetary science and exploration at the Open University in the UK. His research is in the Solar System, but particularly in water and associated materials in other systems. Mahesh gets to study rocks brought back from the Moon, and also material from Mars and asteroids, looking into the make-up of the Solar System. He has also studied some of the rocks the Apollo astronauts brought back from their missions.

NASA has said it wants to put humans on the Moon by 2024, and it's ambitious. It's got to find the funding, but certainly the world's agencies are going back to the Moon, and we will see that in the coming years. It's a hugely exciting time in space exploration, and I can't believe I get to be a part of it either really.

Can you tell us briefly about the Lunar Gateway? Is it going to orbit the Moon or will it be on the lunar surface?
LJ: It's going to be orbiting the Moon in a very elliptical orbit. So not like we're used to now, with the International Space Station going around the Earth, but it's going to be much smaller than the International Space Station. The ISS is about 100 metres [330 feet] long, and the size of a five-bedroom house. This Gateway is going to be like a bijou studio flat.

The science capacity with it at the minute, we're talking about a metre [three feet] cubed - it is tiny. But it will allow us to be a staging post to return humans down to the surface and to let us study the Moon and Earth and learn how to live in that very strange environment beyond the safety of our magnetic field, which protects us from all the cosmic radiation.

How far have we come in sending humans safely into space and back home again since Apollo 11?
LJ: It blows my mind that we went from no humans in space in 1961, the beginning of that year, to eight years later, humans on the Moon. I've been working in the space industry my whole career, and we've not done anything like that. I was saying 2024, five years away, that's challenging. It is unbelievable what they did with the technology that they had then, but it was that naivety, that challenge, that risk that took them there. I still can't believe, when you look back at it now, what was achieved.

What's changed since then? Have we become more risk averse?
LJ: What drove the Apollo Moon landings was political, and huge amounts of money went into it. If we put that amount of money into the manned space programme today, we could do it again, but there are other challenges. Other things that we want to spend - should be spending - taxpayers money on as well. It's a question of political as well as scientific demand, and all of these things at different times come together. We've learnt now how to live and work in low-Earth orbit on the International Space Station. So really, we've had this horizon goal of getting humans to Mars, and the Moon is the next step on that journey.

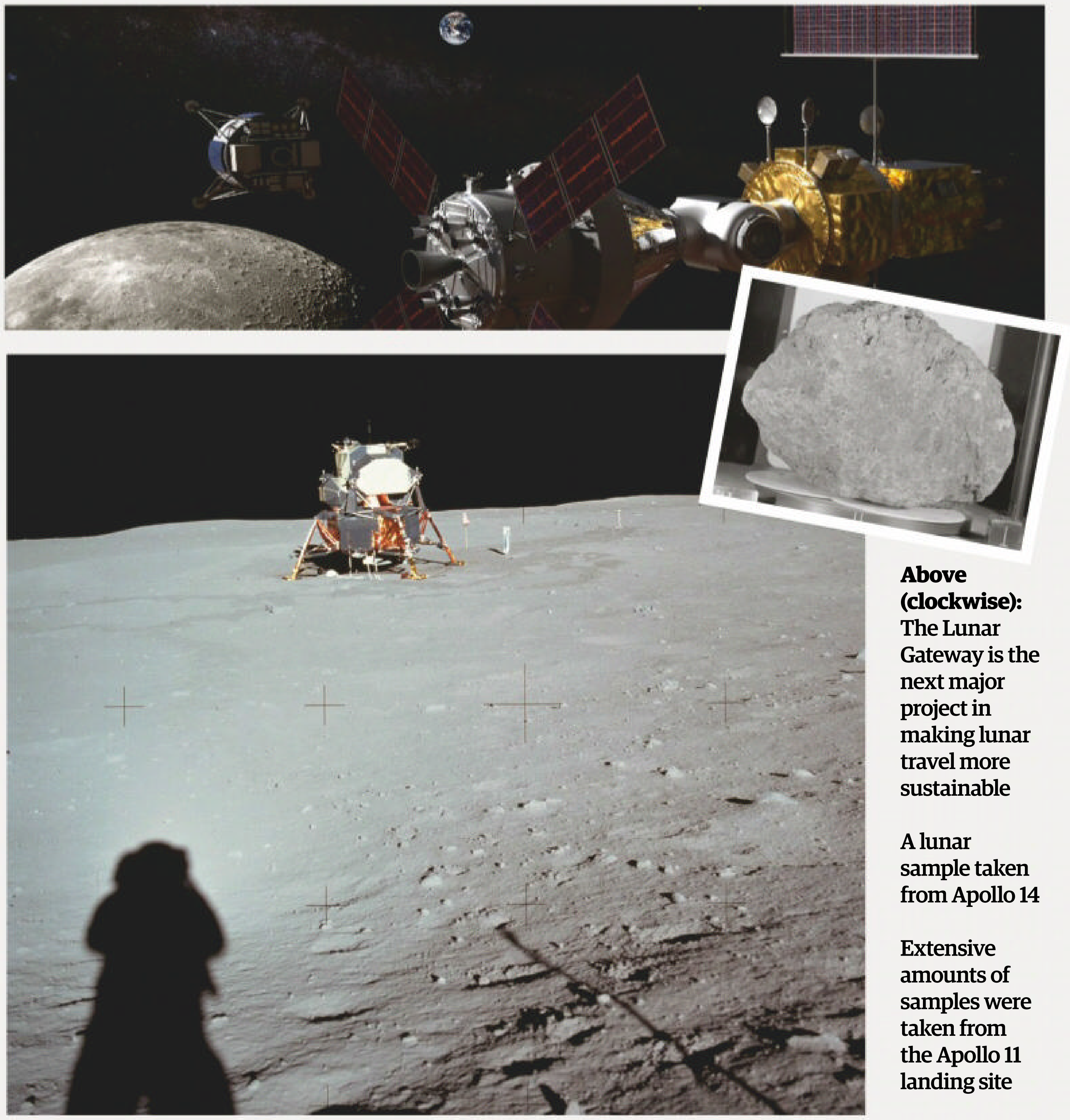
If we get to go back to the Moon and carry on that work, what kinds of things can we learn?
MA: One of the things that I mentioned, that in the last ten years we didn't know about for 40 years. We had those samples in 1969, but it was not until 2008 that it became obvious that those rocks did contain water. Yes, and you may ask, "Why didn't we know?"

Well we didn't know because we didn't have the technology. Also another reason is about human behaviour, as we are very set in our ways and the way we do things, right? If somebody says that this thing is this, we don't question it often. Because as soon as the Apollo samples came back in the 1960s and early 1970s, they didn't know there was water in those samples because they didn't find them, because they didn't have the right technologies or they didn't look hard enough with the technology that they had. Some people actually did find that it looked like water on Earth. And so they said: "No, that is contamination from somewhere in Houston [Texas] or Pasadena [California], and Moon has no water. It's dead."

It took 40 years for somebody to question that. We could question that because we now have much more sophisticated instrumentation, much more sensitive instrumentation and a better understanding of what we are looking for. Lo-and-behold, we did find water in the Moon, and that was a game-changer. Now we are trying to understand where this water came from.

It also turns out that the water on the Moon is very similar to water on Earth. So it is a surprise that in 1960, people did find some water. They just couldn't commit [to the idea] and they just thought it was from Earth, so why is it that important.

Is there a practical importance in using the water found on the Moon?
LJ: That is one of the challenges that we've got. In fact, the missions, as I mentioned, at the minute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Above (clockwise): The Lunar Gateway is the next major project in making lunar travel more sustainable

A lunar sample taken from Apollo 14

Extensive amounts of samples were taken from the Apollo 11 landing site

Relive Apollo 11

8 Days: To the Moon and Back, a drama-documentary by the BBC which uses the declassified audio from the Apollo 11 mission and retells the world's most famous story of high-stake exploration, is a new and innovative way to tell the tale. Available on BBC iPlayer.

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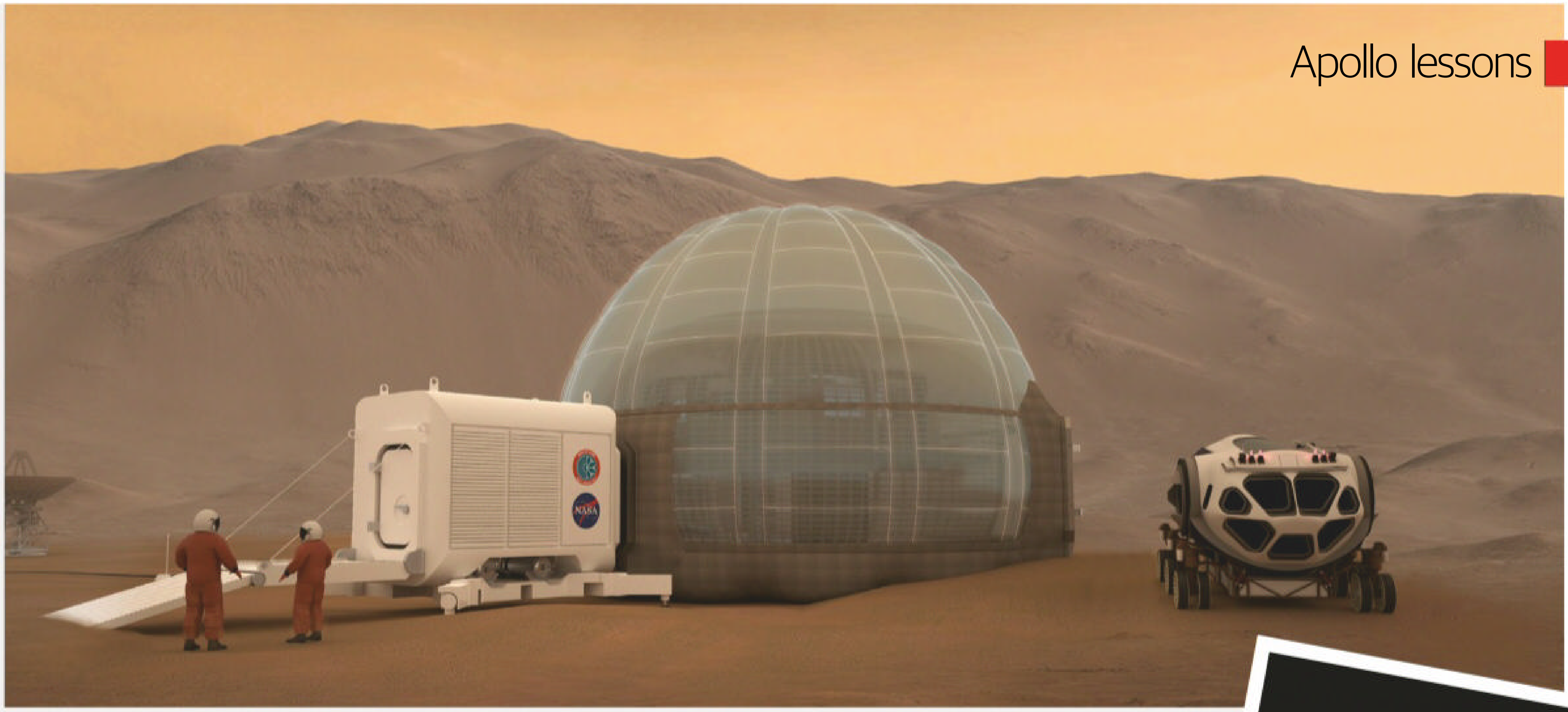

© NASA

that are being developed at the Open University, it's all about looking at the wonderful lunar volatiles, which is water and other things. Can we go and extract them? Could we use them to support astronauts on the Moon and sustain exploration further out into the Solar System?

If we do that, it will help astronauts on the Moon, but we will also discover all kinds of new technology as we're doing it, which helps us back here on Earth.

The samples that come from the Apollo missions: how are they shared around the world?
MA: We are so grateful to NASA, because, of course, the American taxpayers paid for the programme, and so they could claim all of the Moon rock they collected are theirs. But what NASA does is that it actually evaluates the scientific merit of each proposal, and it doesn't matter where they are proposed from, as long as those scientific investigations are peer-reviewed and found to be worth supporting, it actually then loans whatever you are requesting.

In some cases I request maybe two or three grams of Apollo 11 rock for example, and I get it. If I say I want five grams of this rock from Apollo 17, I get it. So it's peer-reviewed and it's purely based on the scientific merit of the individual proposal.

What elements are in the Moon rock?
MA: In short, the Moon rocks have all the elements that you find here on Earth.

When you have the Moon rocks, what do you look for and measure in them?
MA: If you're looking at a Moon rock that was collected by the Apollo astronauts, you already have a lot of information, because so much work has already been done on Moon rocks that were collected by the six missions. Whereas if you have a lunar meteorite, you really don't know where on the Moon it is from, so you really need to look for everything. But to begin with you want to understand what this rock is made up of, and then slowly you build up a story. You want to know how long ago it actually formed, where it has been, what it is telling us about the Moon's geological history. It's like piecing together different pieces of evidence to build up your story, and then being able to narrate to somebody who can say, "I can find this flaw in your logic." Then you go back to the drawing board and find some more information, and then you keep building on. That's what we do all the time.

Right top (clockwise): Colonising Mars is the next big step in manned space exploration

ESA will soon have a lander on the Moon for the first time

Tourists will soon be paying commercial companies to take them into space

© Blue Origin; ESA

"NASA has said it wants to put humans on the Moon by 2024, and it's ambitious. It's got to find the funding"

How can our readers become an astronaut?
LJ: It is such an exciting time, and you've got several different options. The European Space Agency, to which the UK is a member of, they hire astronauts about every ten years, but we might see that change in the future. Those people have technical degrees. But really, beyond that they are just really good at what they do, and the best advice to anyone who wants to be an astronaut is to go and do things you enjoy and do them as well as you can. Then when you find yourself age 30 and they're looking for astronauts, apply and see how you do.

But you could also start saving. We're at this time now where there are commercial companies who started to sell tickets to go into space, whether that's the suborbital companies like Virgin Galactic taking people into space for about six minutes and you float and see the Earth, or if you're really rich you'll start to be able to buy seats to go to the International Space Station. So start saving your pennies now, and you might even be able to buy a ticket and go into space one day.

Are there any plans to explore land in the polar craters that do not receive light?
LJ: You'll be pleased to know we are. We are going to the South Pole-Aitken Basin, where there's not much light and we think a lot more water, which is really interesting. The NASA plans are to get people down to that south pole; we will see this new chapter of lunar exploration is absolutely looking at those regions with a lot of interest.

NEMESIS

THE SUN'S EVIL TWIN?

Since the 1980s, astronomers have explored the possibility that our star was not born alone

Reported by David Crookes

What do you get if you cross the dinosaurs with millions of comets and an evil twin of our Sun that has not only wreaked havoc on Earth multiple times but has long been hidden from view? Anxious? Fearful? Maybe both? For while it may sound like a terrible joke. The intriguing punchline once caused some alarm – and raised a mystery that had astronomers hooked for quite some time.

Welcome to Nemesis, the Sun's hypothetical long-lost companion which has been speculated to be circling in the edges of the Solar System. Proposed by Richard A. Muller, an American physicist and professor of physics at the University of California, Berkeley, it gained some ground in the 1980s with the suggestion that it was behind a series of mass extinction events here on Earth.

The theory grew from a 1983 study by two palaeontologists, David Raup and Jack Sepkoski. They had analysed the extinction rates of 27,000 marine animals which perished during the past 250 million years and pointed towards five mass wipeouts since the Late Permian era, in which more than 75 per cent of species disappeared. They went on to suggest that these catastrophic extinction events were uniformly spaced, taking place every 26 million years, but scientists could not quite fathom why.

Various studies emerged looking at phenomena on Earth, but the belief that a large asteroid wiped out the dinosaurs – a hypothesis by Luis and Walter Alvarez in 1980 – suggested extraterrestrial forces could be at play. It was on this basis that Muller came up with the idea that the comet which smashed into Earth 66 million years ago had been among a humongous group of bodies disrupted by a theoretical red dwarf star. He said it affected the orbits of these objects and sent them

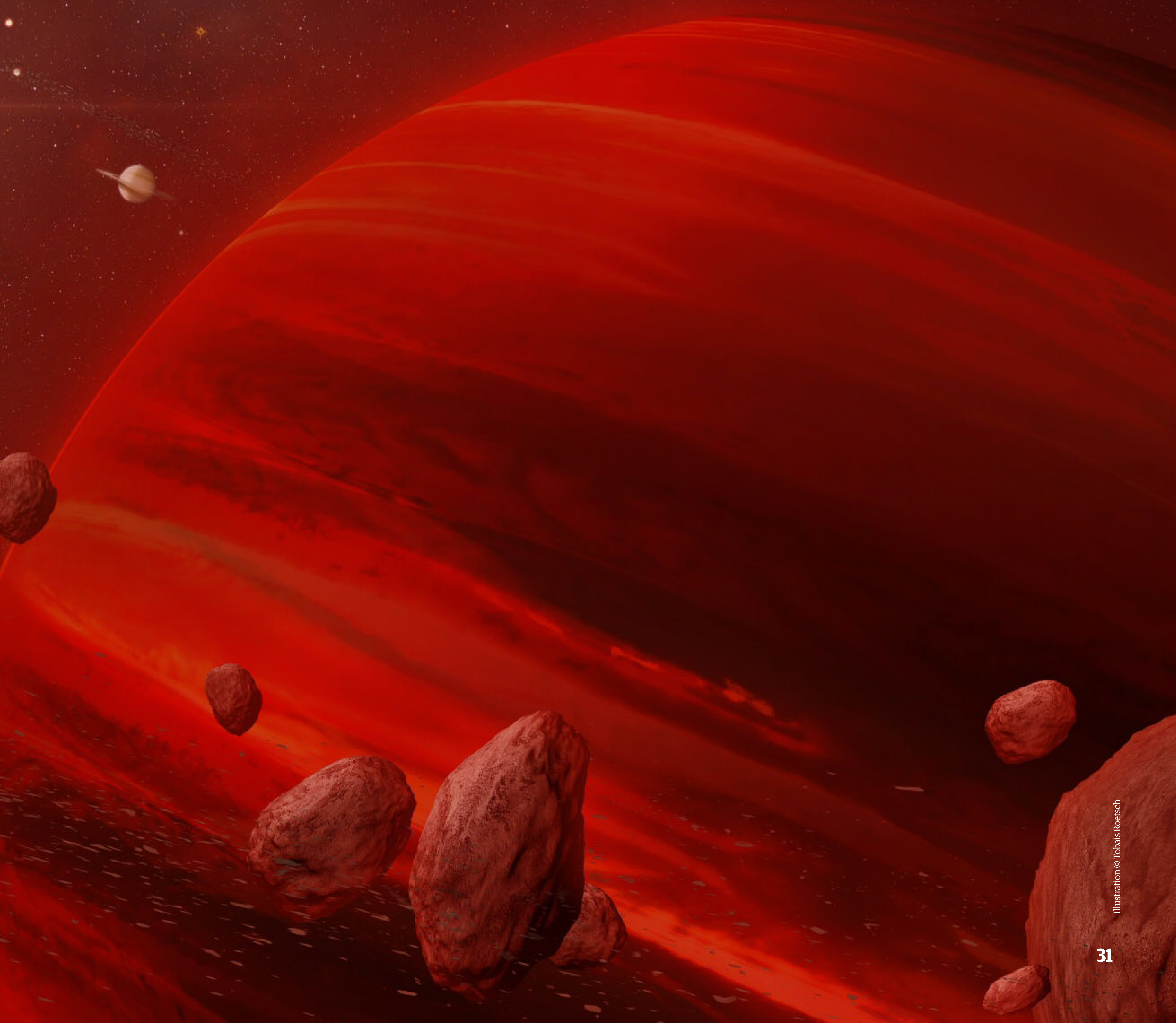


Illustration © Tobais Roetsch

hurtling towards our Sun, smashing into whatever they encountered.

That in itself would have been rather eye-catching, but here is where things became even more interesting. Muller's theory postulated that this star was the Sun's undetected companion - the 'evil twin' that we alluded to at the start. He also reckoned the reason why there may have been this notable cycle of mass extinction events was because the red dwarf star was regularly putting itself among the set of icy rocks that make up the equally theoretical Oort Cloud in the outermost reaches of the Solar System.

It would do so every 26 million years, he says, neatly accounting for the calculated apocalyptic timeframe on Earth. But in order to do this the red dwarf star needed to be in a 1.5 light year elliptical orbit, periodically bringing it closer to the Oort Cloud and sending comets hurtling our way. What's more, the theory continued, there was enough of a gravitational pull on the 'death star' by the Sun to prevent it from drifting away.

When Muller presented his hypothesis in 1984, it caused international controversy. The scientist was suggesting that the companion star was born at the same time as the Sun, and so was part of a binary star system - that is, one gravitationally bound and orbiting a common centre of mass. Yet in the last 35 years there has never been any sighting, even though it's not been for a lack of trying.

In many ways this is rather odd. Muller said Nemesis was likely to have a magnitude between seven and 12 and that it should be possible to view it through a small or medium telescope. But the Infrared Astronomical Satellite - the first space telescope to perform a survey of the night sky at infrared wavelengths - did not see any signs of it during the 1980s, while the Two Micron All-Sky Survey, or 2MASS, which surveyed the sky between 1997 and 2001, couldn't detect an additional star in the Solar System either.

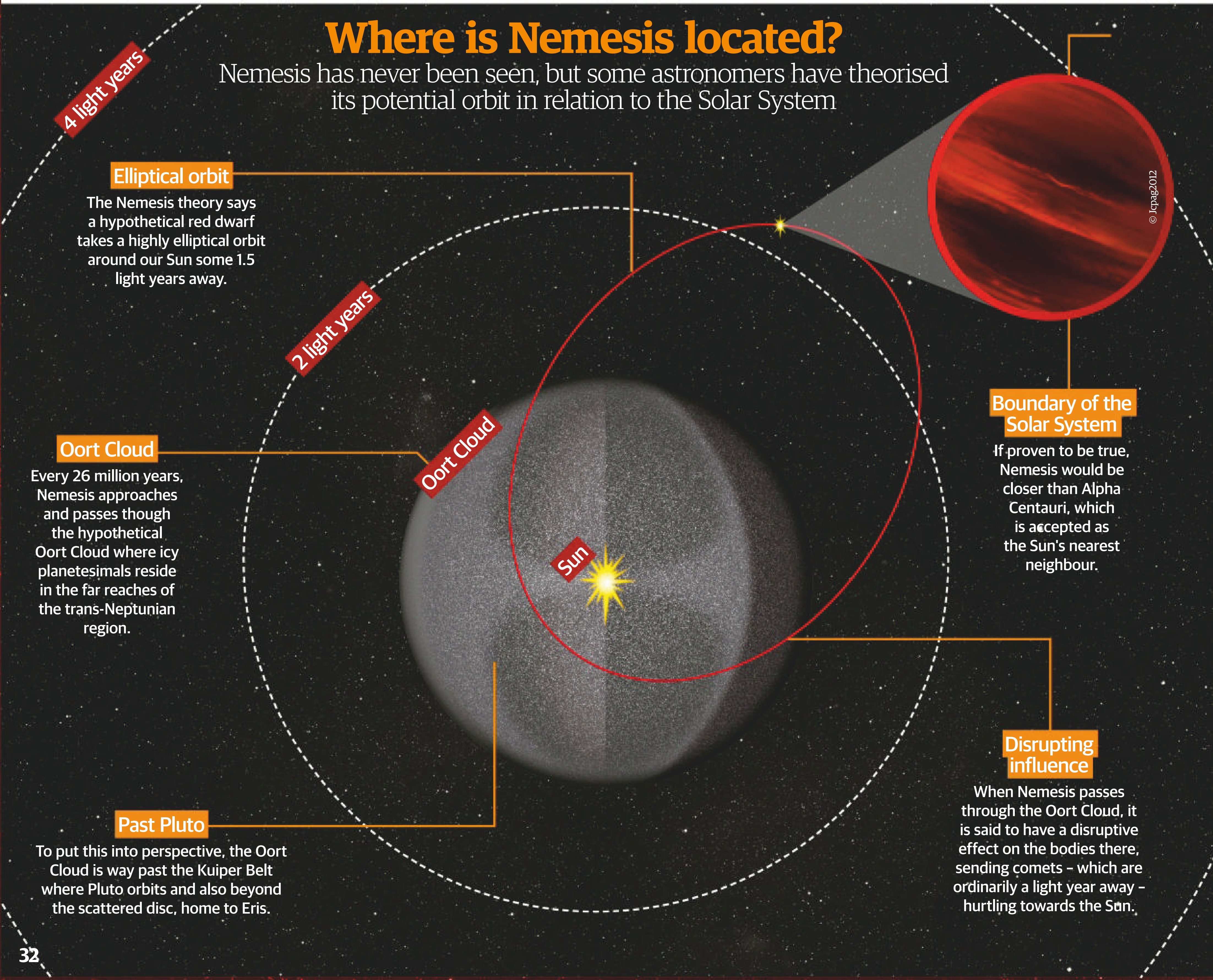
The best shot was thought to be NASA's Wide-field Infrared Survey Explorer (WISE), which spotted a brown dwarf 7.2 light years away in 2014. But it wasn't Nemesis. In actual fact, when Kevin Luhman, an astronomer at Pennsylvania State University's Center for Exoplanets and Habitable Worlds, analysed images from WISE a year earlier in the outer Solar System, there was simply no sign of the companion star that Muller had proposed.

Instead, evidence kept stacking up against it. For starters, some astronomers questioned the inherent

> "Stars generally do not form in isolation but are born together in groups within clouds of gas and dust or nebulae" **Pavel Kroupa**

Where is Nemesis located?

Nemesis has never been seen, but some astronomers have theorised its potential orbit in relation to the Solar System



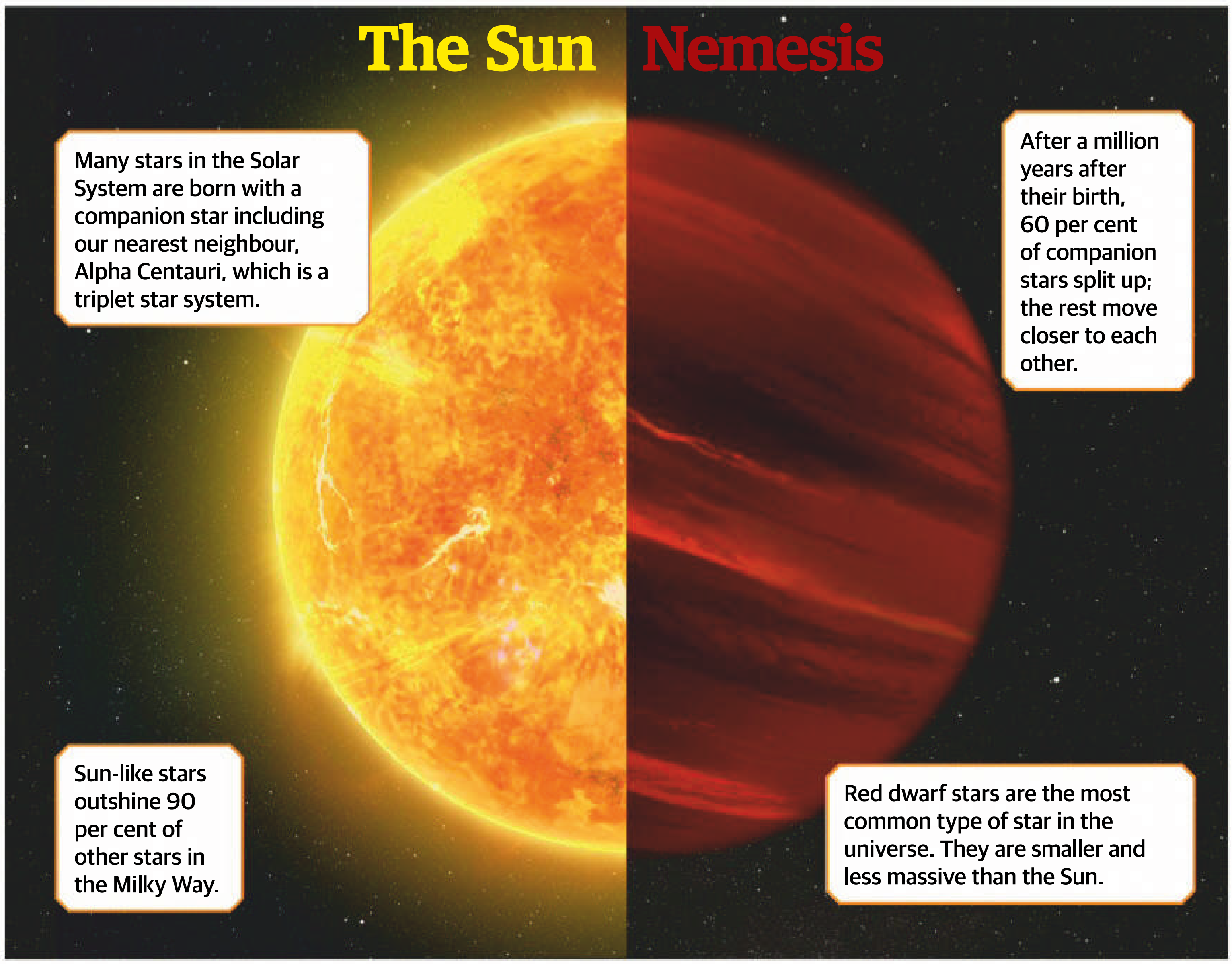
Elliptical orbit
The Nemesis theory says a hypothetical red dwarf takes a highly elliptical orbit around our Sun some 1.5 light years away.

Oort Cloud
Every 26 million years, Nemesis approaches and passes though the hypothetical Oort Cloud where icy planetesimals reside in the far reaches of the trans-Neptunian region.

Past Pluto
To put this into perspective, the Oort Cloud is way past the Kuiper Belt where Pluto orbits and also beyond the scattered disc, home to Eris.

Boundary of the Solar System
If proven to be true, Nemesis would be closer than Alpha Centauri, which is accepted as the Sun's nearest neighbour.

Disrupting influence
When Nemesis passes through the Oort Cloud, it is said to have a disruptive effect on the bodies there, sending comets – which are ordinarily a light year away – hurtling towards the Sun.


The Sun
Nemesis
Many stars in the Solar System are born with a companion star including our nearest neighbour, Alpha Centauri, which is a triplet star system.
After a million years after their birth, 60 per cent of companion stars split up; the rest move closer to each other.
Sun-like stars outshine 90 per cent of other stars in the Milky Way.
Red dwarf stars are the most common type of star in the universe. They are smaller and less massive than the Sun.

© Tobias Roetsch

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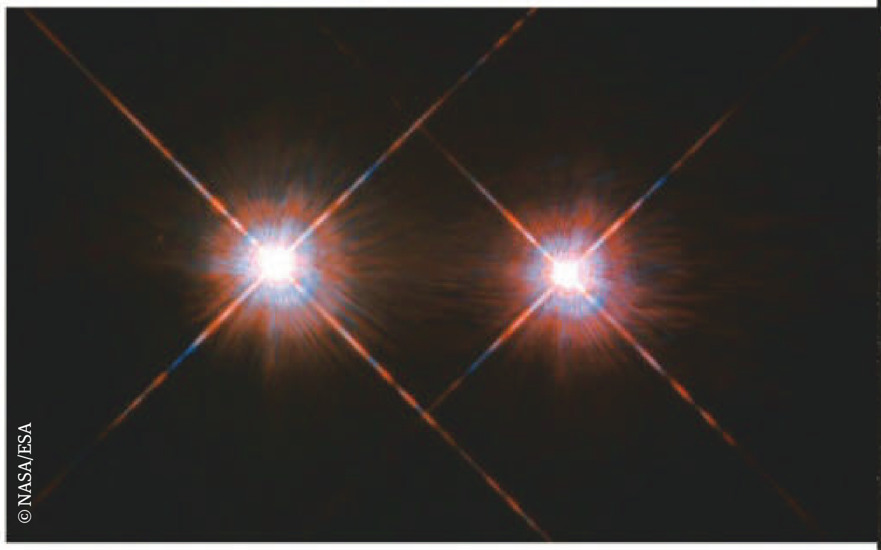

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stability of Nemesis' proposed orbit. They said the star would come within the gravitational pull of other stars moving through the galaxy. Others cast doubt that extinction events follow a set cycle. "There is a tendency for people to find patterns in nature that do not exist," said Coryn Bailer-Jones from the Max Planck Institute for Astronomy in 2011. "Unfortunately, in certain situations traditional statistics plays to that particular weakness."

Bailer-Jones said the impact rate of asteroids and comets had been judged to be steadily increasing over the past 250 million years on the basis of the number of craters of different ages. But he argued that periodic variations could be ruled out: "From the crater record, there is no evidence for Nemesis," he concluded. "What remains is the intriguing question of whether or not impacts have become ever more frequent over the past 250 million years."

On that basis it is surely a matter of 'case closed'. Here we have an intriguing idea that many of us would wish to be true, and yet in reality it sounds merely fantastical, with evidence that is flaky at best.

But that isn't telling the full story, and there has been a little matter of a dwarf planet called Sedna to consider, which some astronomers reckoned was additional proof of a twin for the Sun. It is, at 8 billion miles away, one of the most distant bodies in the Solar System, and it pursues an extremely elongated orbit. Discovered in 2003 by a team led by Mike Brown, an astronomer at the California Institute of Technology, it has certainly caught the imagination, but what does it really prove?

Well, there has been a theory that Sedna's wonky orbit could only be the result of a large and distant binary companion to the Sun pulling it out to such a distance. What else, scientists argue, could take the dwarf some 200-times further from the Sun than Neptune every 11,400 years? A study in 2015 seemed to lend credence to this argument

Above left: An infrared sky survey by WISE failed to discover evidence of Nemesis

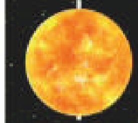
Above right: Binary star systems are not uncommon - the closest to us is Alpha Centauri A and B, along with faint red dwarf C

The theories

Is there really something big and influential somewhere out there causing mass extinctions?

The Nemesis theory

Richard A. Muller's theory suggests the Sun has a companion red dwarf star named Nemesis which has an unusual orbit and causes mass extinctions on Earth every 26 million years or so by having a chaotic impact on bodies in the Oort Cloud.

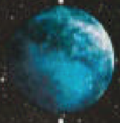


Our dangerous Sun

In 2008, a computer simulation by researchers at Cardiff University suggested our Solar System bounces up and down through the plane of the galaxy. Gravitational forces may dislodge comets from the Oort Cloud and send them cascading inwards.

A brown dwarf

Nemesis may not be a red dwarf, but a brown one. If that was the case then it would go some way towards explaining why astronomers have struggled to see it: brown dwarfs have a low intrinsic brightness, making them harder to discover.



Other planets

There is an acceptance that there are other planets in the outer region of the Solar System. These have never been found, although computer simulations continue to rule in the possibility that they are out there exerting a gravitational influence.

Gas giant Tyche

Scientific analyses suggest extinctions on Earth don't happen at regular, repeating intervals. Some astrophysicists propose a less disruptive gas giant in the Oort Cloud instead, dubbed Tyche - a Greek goddess who was the 'good sister' of Nemesis.

© Tyrogthekreeper

Evidence for Nemesis' existence

Although yet to be proven, there are signs pointing towards a twin star

Companion stars do exist

We know that many stars have a companion, but in 2017 it was suggested that pretty much every star like the Sun had one. Indeed, Sarah Sadavoy and Steven Stahler argued the case for our Sun's companion, but said the partner separated shortly after formation.

Other binaries have similar effects

In 2006, debris discs around two nearby stars were seen by researchers at the University of California, Berkeley, to resemble the Kuiper Belt with a sharp outer edge. It was proposed that a companion star causes this effect.

The presence of Sedna

A trans-Neptunian object called Sedna has an unusual elliptical orbit around the Sun, and some say this is due to the influence of a potential binary companion. Sedna, with an orbit of 12,000 years, has been heralded as strong proof of a companion star for the Sun.

It is just too far away

It's not evidence per se, but the Sun's companion star – at least following Sadavoy and Stahler's model – could now be thousands of light years away, which accounts for why it has never been seen.

© NASA/JPL-Caltech

> "We think the Sun's companion drifted away billions of years ago, within a million years after the Sun and its companion formed" **Steven Stahler**

when Lucie Jílková of Leiden Observatory in the Netherlands suggested a passing star flung it into interstellar space when the Sun was very young.

Yet today Brown tells us that he's not too certain about such theories. "Sedna's orbit is most likely caused by Planet Nine," he says, referencing a hypothetical planet in the outer region of the Solar System. In that sense, he believes there simply is no Nemesis.

"Very sensitive searches have failed to discover it," he affirms. "And, more importantly, the idea that there was periodic extinction appears to have been a misinterpretation of the data. So I think there is both no Nemesis and no need to explain the data! I'm also pretty sure that Nemesis hasn't been a viable hypothesis for more than a decade."

Even so, the case remains open because the hypothesis of a companion star has actually moved on in recent years. While the original theory of Nemesis is perhaps not as strong today as it previously has been, there remains a firm belief in some quarters that the Sun was not born alone.

In 2017, Sarah Sadavoy and Steven Stahler carried out a study called 'Embedded Binaries and their Dense Cores'. Sadavoy, then a radio astronomer from the Max Planck Institute for Astronomy and Stahler, a theoretical physicist from the University of California, Berkeley, discussed how radio surveys of a giant molecular cloud filled with recently formed stars in the constellation Perseus led them to theorise that all Sun-like stars are likely to have been born with companions.

"I do believe this," Stahler tells **All About Space**. "The fact was already known for massive stars, and in 2017 Sarah Sadavoy and I provided strong evidence that low-mass stars like the Sun also tend to form with a companion." In the case of the Sun, this happened 4.5 billion years ago and meant it was born along the same lines as our nearest neighbour, Alpha Centauri, which is a triplet system.

"I believe there was probably a Nemesis a long time ago," he says, explaining that the mathematical

Illustration © Tobais Roetsch

Left: Sarah Sadavoy and Steven Stahler say low-mass stars are always born with a companion but are likely to split, like the Sun

Right: The cold dwarf planet Sedna is said reside at the outer edges of the known Solar System from where the Sun appears as an extremely bright star

Below: It was thought that the Sun's hypothesised twin, Nemesis, caused disruption to icy rocks in the Oort Cloud, causing chaos on Earth

© NASA/JPL-Caltech

model explaining the Perseus observations would only be possible if Sun-like stars are born with a companion. "We showed that probably all stars like ours form with companions," he tells us, "but that most, including the Sun, then lose those companions within the next million years."

The work built on that of Pavel Kroupa of the University of Bonn, whose computer simulations in 2011 led him to conclude that all stars are born as binaries. "Stars generally do not form in isolation but are born together in groups within clouds of gas and dust or nebulae," Kroupa wrote. "These stellar labour rooms produce binary star systems, which means that virtually all newborn stars have a companion. Most of these groups of stars disperse quickly so that their members become part of the galaxy."

In the case of Nemesis - or at least in the case of Sadavoy and Stahler's version of a companion Sun - the Sun's sibling escaped and mingled with other stars in the Milky Way. Stahler says he doesn't subscribe to the view that it then caused strong comet activity in the Oort Cloud. "20 years ago astronomers thought so, but few people believe that now," he affirms. Neither does he believe that the Sun has any influence over its companion.

"Muller's theory is different," he explains. "He postulated that the Sun currently has a companion on an eccentric orbit but, despite a lot of effort, this companion has never been found." Stahler is unsurprised that a form of Nemesis has never been discovered, though. "We think the Sun's companion drifted away billions of years ago, within a million years after the Sun and its companion formed," he says. "It could now be on the other side of the galaxy."

Such findings have wide implications, and they go to the heart of the origins of galaxies. In the case of Perseus there were 45 single-star systems, yet all but five of the 55 young stars in 24 multiple-star systems were binary. More than that, all of the widely separated binary systems - which are those with stars separated by more than 500 AU - were young systems.

"Our finding that most stars are born with companions is interesting for those of us who think about stellar birth," Stahler says. "Apparently our Sun, and also the Solar System, was born from an elongated gas cloud that formed another star - and perhaps another planetary system - as well. We see lots of such clouds, so studying them will tell us the conditions under which we formed."

It's the most compelling evidence that our Sun was once part of a binary star system, but the emphasis on 'once' cannot be stressed enough. As for the figure of 26 million years, well, that too is in doubt, with Adrian Melott and Richard Bambach having argued in their paper, *Nemesis Reconsidered*, that "the orbit of a distant companion to the Sun is expected to be perturbed by the galactic tidal field and encounters with passing stars, which will induce variation in the period".

What all of this means is that the Sun's potential twin is off the hook with regards to it being a mass-murderer, but there is great weight to Muller's assertion that the Sun was born with a companion. Unfortunately it'll be so far away now that we're unlikely to ever see it, it's history perhaps forever keeping us in the dark.

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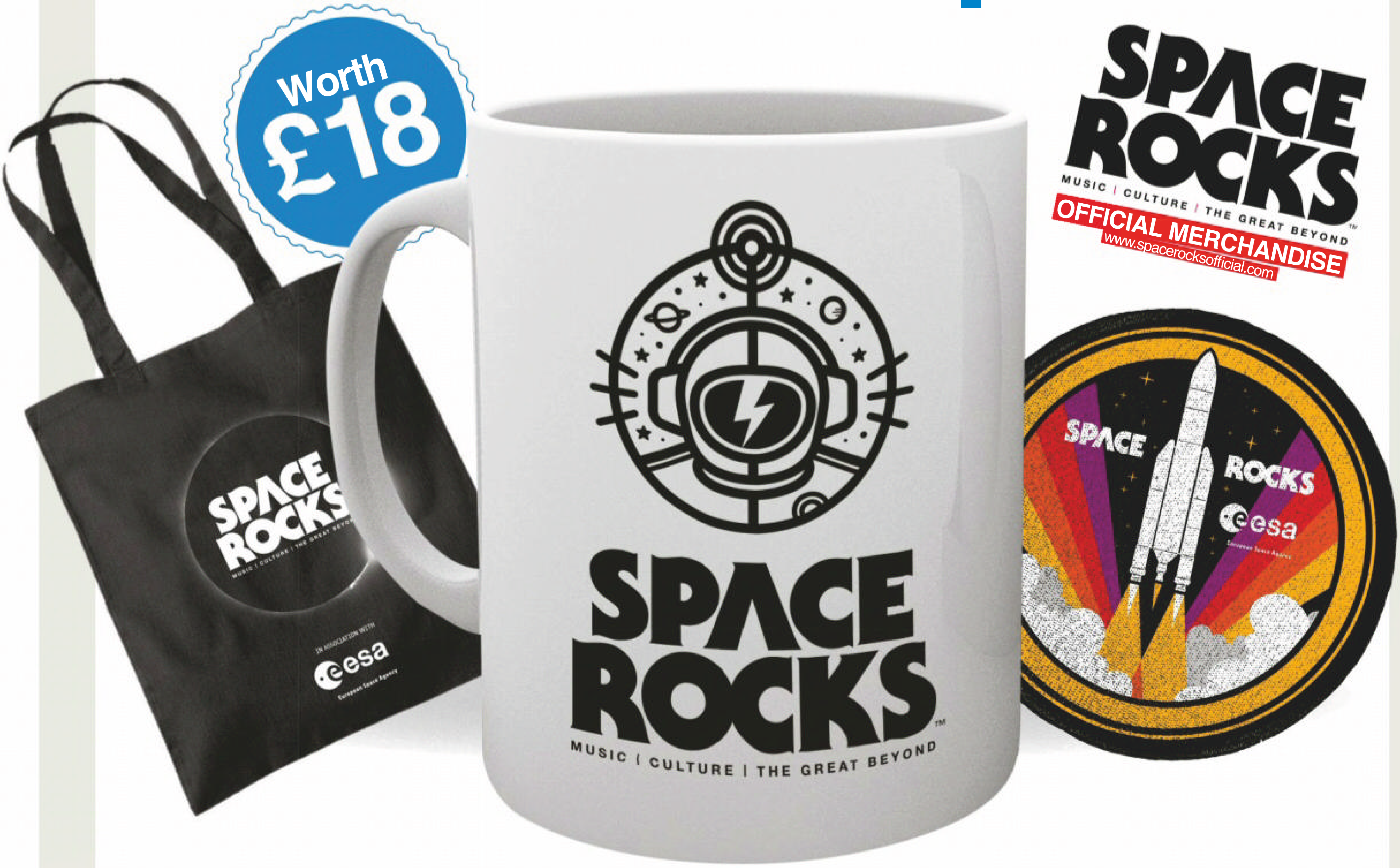
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Gemma Lavender, Editor-in-Chief

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Who killed Tycho Brahe?

Just why one of the greatest astronomers of all time has been at the heart of a centuries-long historical mystery

Reported by Giles Sparrow

Next time the Moon is close to full, grab a pair of binoculars and take a closer look. The most obvious feature of all, standing out brightly amid the grey lunar plains, is a large, prominent crater surrounded by a bright series of streaks that radiate in all directions. Since the first maps of the Moon were made in the mid-17th century, this crater has been named in honour of Tycho Brahe, the Danish stargazer who brought new precision to astronomy and paved the way for the discovery of the laws of planetary motion and gravity itself.

'Tycho is world-renowned for his contribution to the foundation of modern observational astronomy," explains Sacha Kacki of France's National Center for Scientific Research (CNRS) in Bordeaux. "But beyond this fact he is also famous because he was a colourful figure who was a hearty eater, drank a lot, lost his nose in a duel and died in bizarre circumstances. The controversy around the circumstances of his death is probably one of the main reasons why he attracted so much interest."

Thanks to recent research by Kacki and others, it seems the truth about that death can now be told - but for the scientists investigating his remains, that's just one part of the story.

Tycho's life was unusual from the outset. Born into a noble Danish family at Knutstorp Castle, now in Sweden, in 1546, he was adopted - some say effectively kidnapped - by a wealthy childless uncle who encouraged his keen mind. By the age of 12 he was already attending the University of Copenhagen, and it was here that a solar eclipse in August 1560 sparked his interest in astronomy.

In the late-16th century, astronomy faced a crisis as the Earth-centred or 'geocentric' view of the universe was challenged by the Sun-centred or 'heliocentric' model promoted by Polish priest Nicolaus Copernicus. Accurate measurement was the key to establishing which view of the universe was most likely to be true, and after further studies at the University of Rostock - the site of the duel with a fellow student over who was the superior mathematician that cost him his nose - Tycho devoted himself to tracking the heavens with new precision. In 1576, King Frederick II of Denmark funded the establishment of a new castle-observatory, known as Uraniborg, on the island of Hven. Tycho's work attracted powerful support because both he and his patrons believed in astrology - a supposed link between events in the heavens and those on Earth.

Despite his astrological beliefs, Tycho made important steps towards a more realistic view of the universe thanks to two spectacular celestial events in the 1570s - a brilliant 'new star', today recognised as a distant supernova, and a large, bright comet. Tycho's measurements showed that both of these objects must lie far beyond the Moon, in a realm that most astronomers had previously believed to be fixed, 'perfect' and unchanging. In 1588 he published a book describing these controversial observations in detail, outlining his own model of the universe. This 'Tychonic' system retained Earth's supremacy at the centre of everything, but had Mercury and Venus orbiting the Sun, even as the Sun itself circled Earth with the other planets.

That same year, however, Tycho's fortunes turned when his patron Frederick II died and his 11-year-

The crater Tycho is one of the most prominent features on the near side of the Moon, with bright rays

© Joe Huber

Most portraits of Tycho choose to overlook the silver artificial nose he wore for much of his life

© Getty

Sequence of events

Just what did happen in Prague, October 1601, over the 11 days leading up to Tycho Brahe's death?

Fateful invitation

1 Tycho Brahe and his friend Councillor Minckwicz attend the banquet of spendthrift and libertine Baron Peter Vok von Rosenberg in Prague. Also present is Tycho's distant Swedish cousin Erik Brahe.

Politeness kills

2 Tycho typically overindulged at the dinner table. However, unable to leave the table to relieve himself due to strict courtly etiquette, he suffers acute bladder pain.

Not a drop

3 On returning home, Tycho is unable to urinate. Kepler reports that he attempts various remedies using medical treatments of the time without success. He is also, understandably, unable to sleep.

Unexpected visitor

4 On 20 October Erik Brahe makes the first of three visits to Tycho's house. It's uncertain whether Tycho was truly recovering at this point, but his health certainly enters its final decline from here onwards.

The suspects

The difficult pupil

Johannes Kepler is often considered the prime suspect. An abstemious protestant and almost a mirror-image to Tycho, some say he killed for unfettered access to the Dane's meticulous observations or to win the post of Court Mathematician. These theories ignore the fact that Tycho had already proposed working as equals on the Rudolphine Tables, and lobbied that Kepler should receive an Imperial post of his own.

The murderess?

Barbara Kepler was already a widow twice over by 23 when she met and married her third husband Johannes. Two of their children also died in infancy, and Danish scientist Bent Kæmpe used this as evidence for her possible role as a 'serial killer', poisoning Tycho out of jealousy and to advance her husband's position. Considering the high mortality rates of the time, her sad family history was not particularly unusual.

The jealous king

Christian IV of Denmark had his opinions turned against the Brahe family by rival counsellors – but could he have ordered Tycho to be killed? One suggestion is that he developed a hatred of Tycho after suspecting – rightly or wrongly – that the astronomer was having an affair with his mother, the dowager queen.

The secret agent

Erik Brahe was a Swedish nobleman and distant cousin of Tycho's, known to carry out secret missions for Christian IV. His surprise appearance at Prague and later visits to Tycho's bedside just as the astronomer was recovering seem suspicious, as do some entries in his diaries from the time. But without scientific evidence for poisoning, can he really be framed as a contract killer?

Illustrations © Ed Crooks

old son succeeded to the throne as Christian IV. A council set up to advise the young king was led by a rival of Brahe's, and relations with the royal court steadily worsened. By 1597 Tycho was driven into exile in Germany, and a couple of years later he took what was to be a fateful new appointment as Imperial Court Astronomer to the Holy Roman Emperor, Rudolph II, in Prague. The emperor, fascinated by oddities such as astronomy, agreed to finance a new observatory near Prague.

In 1600, Tycho was joined there by a new student - a young German called Johannes Kepler. Kepler was a brilliant mathematician and had his own theories about the mystical geometry of the universe that he hoped to test against Tycho's observations. Relations between the two men were not always easy, however.

Plans for the new observatory were disrupted when Tycho's capricious new master summoned him to Prague to provide astrological advice. He reluctantly moved into the emperor's Summer Palace, and it was here, in October 1601, that Tycho died in circumstances that have raised suspicions and doubts ever since.

The sudden decline began after he attended a banquet at the invitation of Peter Vok von Rosenberg, a wealthy nobleman whose palace sat at the gates of Prague Castle, on 13 October. According to Kepler and others, strict etiquette forbade anyone from rising from the table before the host. Tycho, who had overindulged in both food and drink, held his bladder in great discomfort rather than risk giving offence. By the time he returned home, he found he was unable to urinate.

In acute pain and unable to sleep, Tycho took a number of his own self-made medicines over the next few days. A physician who examined him attributed his symptoms to kidney stones, but despite various attempts at treatment there was no further improvement. Bedridden and increasingly delirious, he summoned Kepler to his side. The emperor had just commissioned him to produce a new set of detailed tables of planetary motion, to be known as the Rudolphine Tables, and Tycho begged Kepler to complete the work, and show how the patterns they revealed would be best explained by the Tychonic, rather than the Copernican system. Kepler, despite his misgivings about Tycho's theories, agreed. The following day, 24 October, Tycho passed away.

Last will

5 By 23 October Tycho is delirious. He summons Kepler to his bedside and begs him to finish their work on the Rudolphine Tables.

Worsening conditions

6 Over the following days Kepler observes Tycho's increasing pain and insomnia. On 18 October, however, he finally squeezes out a few drops and is able to sleep.

Declared dead

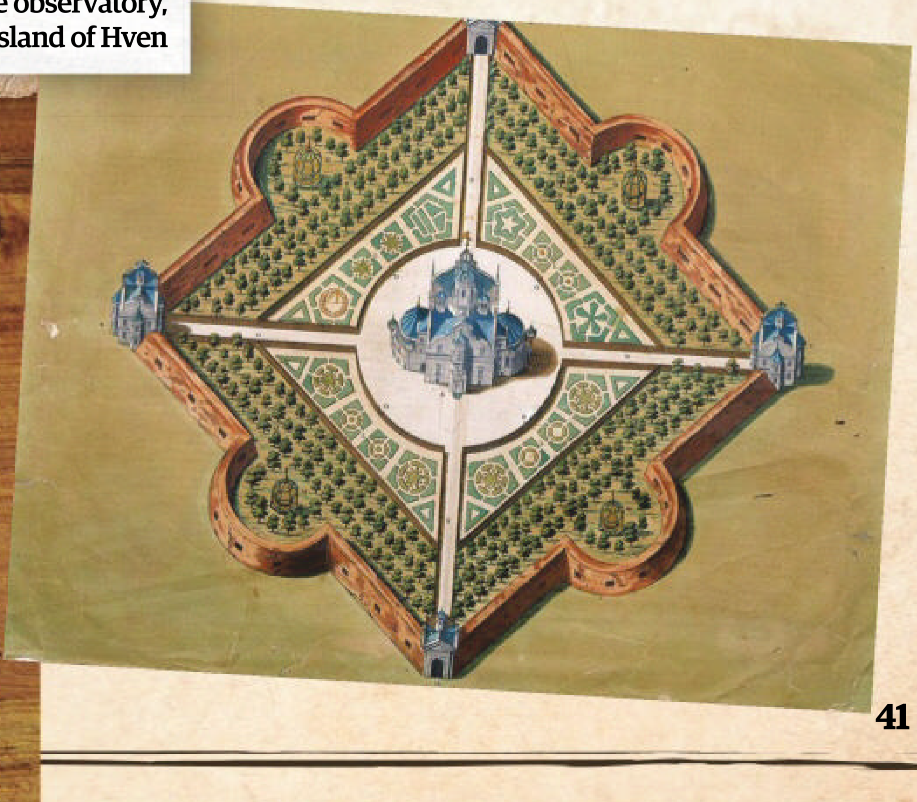
7 Tycho passes away on 24 October, aged 54. A physician attributes his sudden decline and death to kidney stones, though no sign of these is found during either the 1901 or 2012 exhumations.

Alchemical experiments

Tycho's lifelong obsession with alchemy involved him tinkering with substances that are known today to be toxic. In pursuit of impossible goals such as the 'philosopher's stone', capable of turning lead into gold, could he have unwittingly poisoned himself? A 2016 analysis showed unusually high amounts of gold in his hair, and Tycho tried a wide variety of medicines to cure his bladder during his last days.

Tycho's lifestyle

As an independently wealthy nobleman, Tycho was used to indulging in food and drink. Trapped in the Imperial Court at Prague with little hope of returning to his new observatory, he seems to have taken solace in the luxurious lifestyle of banquets, rich food and richer wine. The latest research by Sacha Kacki and his colleagues suggests this could have led to diabetes and other disorders.



This plan shows the layout of Tycho's castle observatory, Uraniborg, on the island of Hven

A portrait from around 1610 captures the fierce intelligence of Tycho's protégé, Kepler

At the time some eyebrows were raised at the speed which Tycho's assistant was elevated to his master's former position of Imperial Court Mathematician. Over the next decade, however, Kepler would earn his own prestigious place in the history of astronomy, completing the Rudolphine Tables and using Tycho's measurements to unearth the previously unsuspected missing key to planetary motion - that objects orbit the Sun not in perfect circles, but moving on elliptical paths.

Suspicions around Tycho's death never quite went away, but they only began to snowball in the 1900s. Doctors in Denmark and Sweden used new techniques to analyse samples taken from Tycho's body when his tomb in the Church of Our Lady before Týn had been opened and the bones examined in 1901. In particular they claimed to find high levels of toxic mercury in his beard. Mercury is known to damage tubules in the kidneys, and can cause a condition called uremia - could Tycho have been poisoned?

Accusations were flung in all directions - one of the doctors involved in the analysis, Bent Kæmpe of the Copenhagen Institute of Forensic Medicine, pinned the blame on Kepler's wife Barbara, while Claus Thykier of the Ole Rømer Museum suggest Brahe might have accidentally poisoned himself. Others wondered whether Brahe had committed suicide in a fit of depression.

However, the most striking accusations were those against Johannes Kepler himself, widely publicised in a bestselling 2004 book, *Heavenly Intrigue*, by writers Joshua and Anne-Lee Gilder. The Gilders suggested that Kepler saw murder as the only route to getting hold of Tycho's measurements, and a path to advancement in Rudolph's court.

As the controversy rumbled on, archaeologist Jens Vellev of Denmark's Aarhus University obtained permission in 2010 to exhume Brahe's body for a second time, taking samples of his bones, hair and clothing before a respectful reburial. For Vellev the project was as much an opportunity to learn more about the conditions of Tycho's life as it was to solve the mystery around his death.

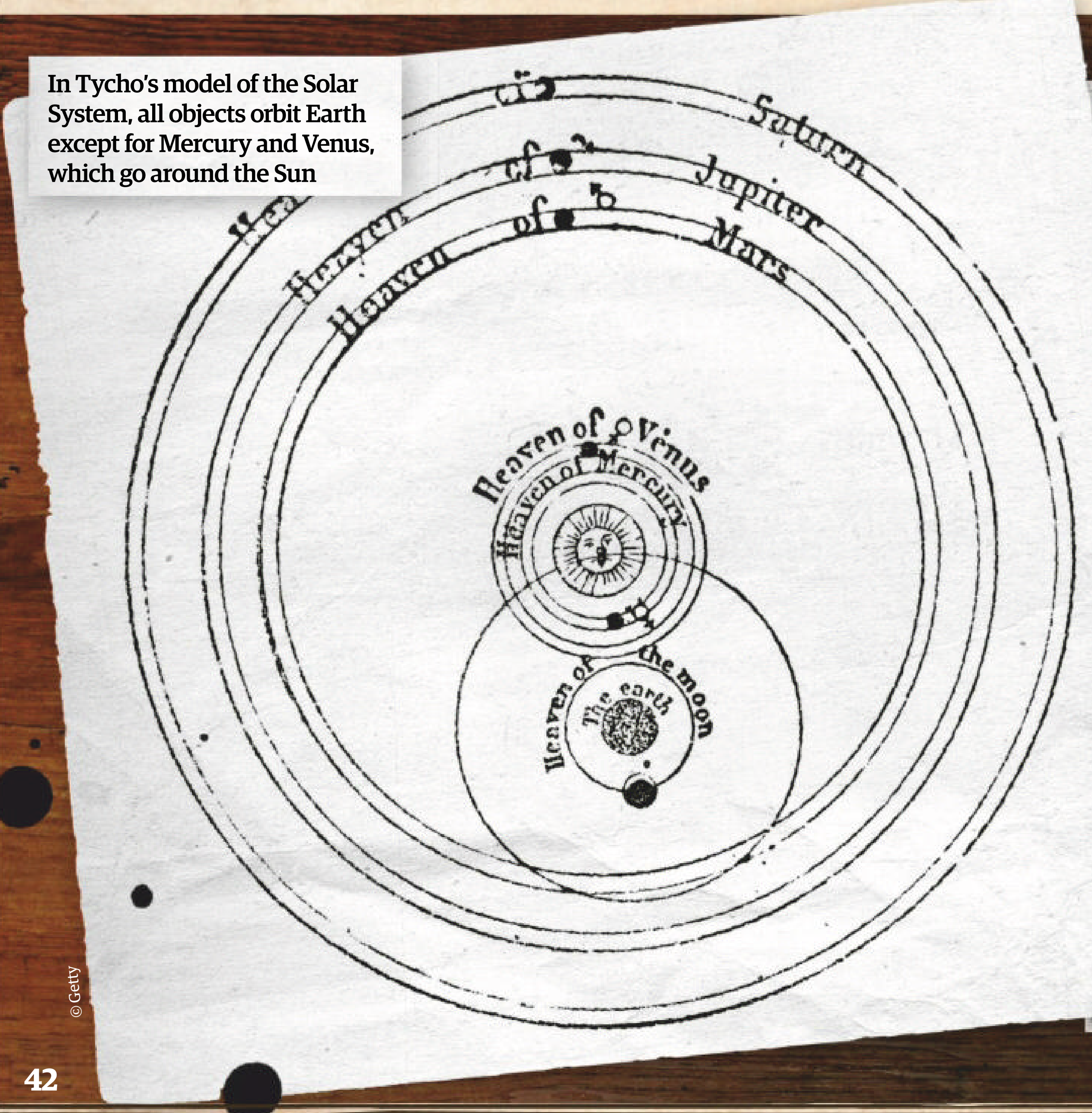
"When we made the new excavation it was not purely because we wanted to find out about how Tycho died," explains Vellev, "but to make a new exploration of the tomb, to see how it was, and to find the clothes and bones to make a new analysis of how he lived."

In 2012 Vellev and his colleagues were able to reveal a conclusive analysis of samples from Tycho's beard. "We measured the concentration of mercury using three different quantitative chemical methods in our labs," said chemist Kaare Lund Rasmussen at the time. "All tests revealed the same result: that mercury concentrations were not sufficiently high to have caused his death."

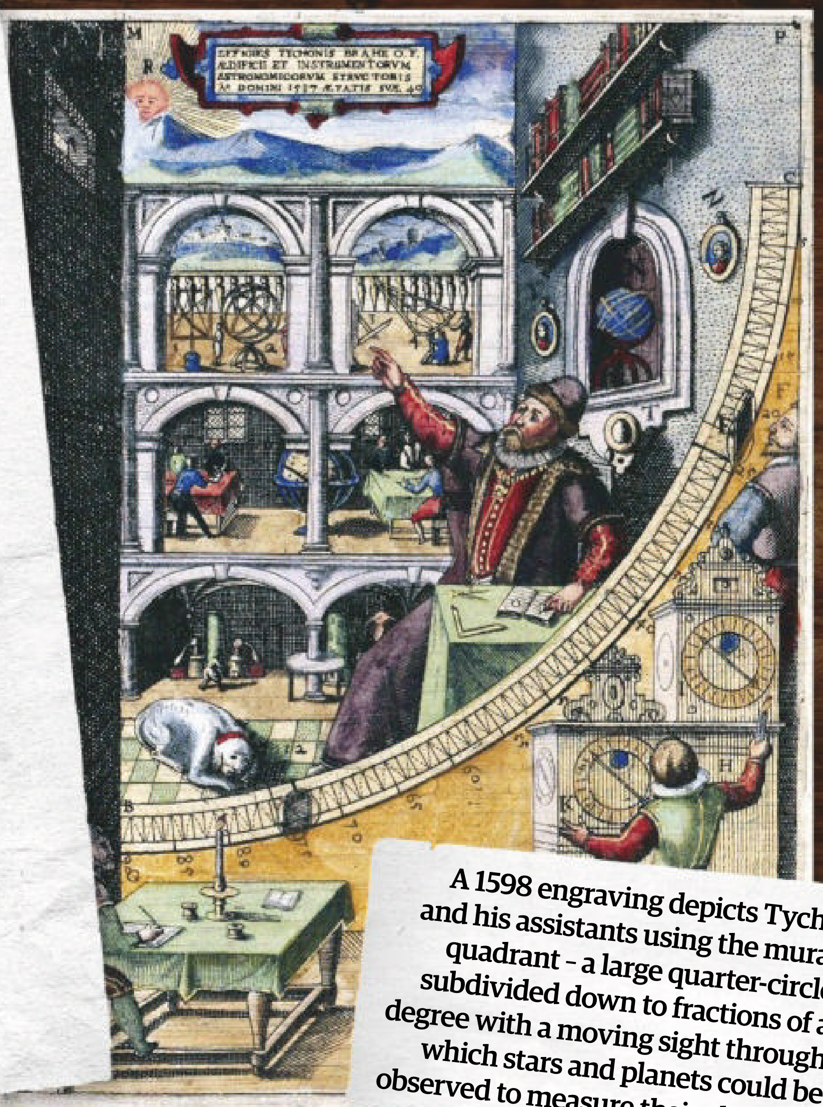
So where had the original researchers gone wrong? It seems the problem lay in a combination of technical challenges, assumptions and exaggerations. Diagnosing mercury poisoning based on random samples of beard hair is a huge challenge in itself - mercury is absorbed into the bloodstream and processed very rapidly, so different parts of Tycho's beard could show very different levels. What's more, some of the scientists involved seem to have started with an assumption that Brahe was poisoned at the banquet, and then looked for evidence of mercury to back it up. The fact that alchemical work exposed Tycho to mercury through much of his life only confuses matters further. On top of that, reviewers of the Gilders' widely publicised book accused them of overstating the level and effect of mercury actually reported in the 1990s analysis.

"As you'd find with you or me, there were small traces of mercury, but we also found gold and silver in pure form and as amalgam," points out Vellev. "We know he made medicines for himself, and so perhaps he took some of his own medicine for his pains before he died, but not in any amount that could have killed him."

> "Suspicions around Tycho's death never quite went away, but they only began to snowball in the 1990s"

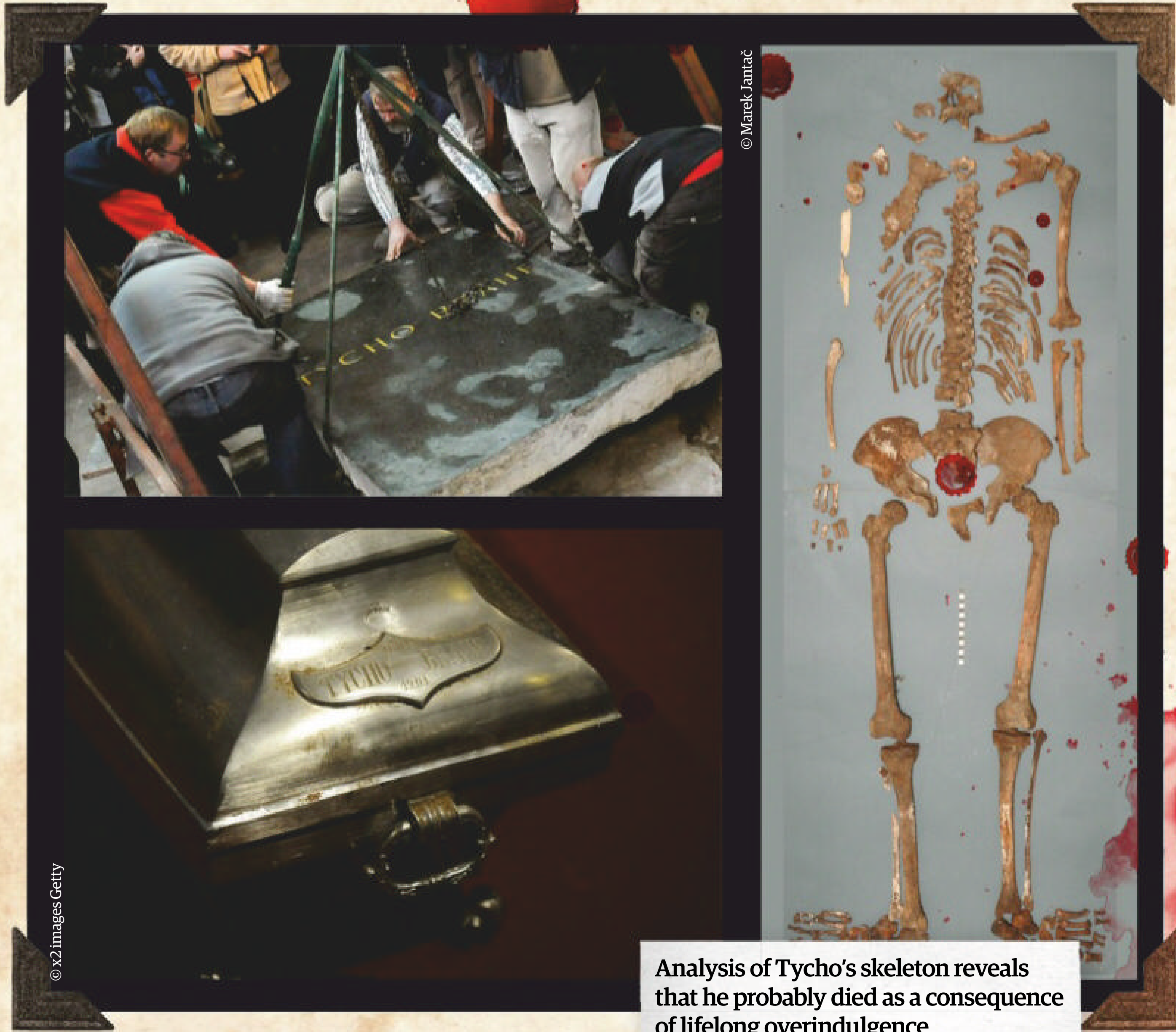


In Tycho's model of the Solar System, all objects orbit Earth except for Mercury and Venus, which go around the Sun



A 1598 engraving depicts Tycho and his assistants using the mural quadrant - a large quarter-circle subdivided down to fractions of a degree with a moving sight through which stars and planets could be observed to measure their elevation

© Getty



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Analysis of Tycho's skeleton reveals that he probably died as a consequence of lifelong overindulgence

Yet despite the lack of evidence to support the poisoning theory, the mystery of Tycho's death seems to run and run. Every few years it seems that a new suspect joins the line-up. The reality of Tycho's death, however, may be rather more mundane - though equally revealing in its own way. A 2018 study by Sacha Kacki and his colleagues points to a variety of long-term health issues that could have led to the crisis in Tycho's health.

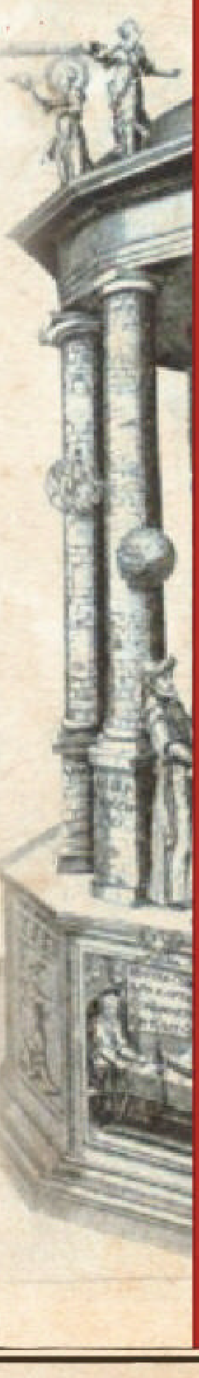
"Our work consisted of a detailed paleopathological examination of his skeleton, along with a reconstruction of his diet and an estimate of his corpulence based on CT scans of his left femur. Our results revealed that Tycho Brahe had a very rich diet with a very high input of animal protein and/or aquatic resources - a diet that had clearly a prestigious character. We also showed that Tycho was obese in the last years of his life."

So did Tycho simply eat himself to death? It's a little more complicated than that, continues Kacki: "Examination of his skeleton further revealed that he suffered from a pathological condition called diffuse idiopathic skeletal hyperostosis (DISH). Although not a life-threatening condition in itself, DISH has various metabolic comorbidities [accompanying health problems] including obesity, diabetes mellitus, gout, hypertension and hyperinsulinemia. Some of these conditions - particularly complications of diabetes mellitus - could well explain the final symptoms before Tycho passed away. Although we can't establish a definite and specific diagnosis, our study points to so-called 'civilisation diseases' as the possible cause of Tycho Brahe's death."

For Kacki's team the new analysis was also to understand more about the typical lifestyle of a Renaissance nobleman. The fact that his life is well documented helped to fill in the picture: "Working on the remains of someone whose life is quite well recorded is indeed interesting, as it allows for a more thorough interpretation of data recorded from his skeleton. As an example, we know that before coming to Prague, Tycho Brahe had his manor and observatory on the island of Hven. This is important information to reconstruct his diet, because marine foodstuffs were likely abundant there, and thus probably played a significant role in the chemistry we have recorded in Tycho's bones."

Jens Vellev, meanwhile, having resolved the 'mystery' of the poisoning, is now immersed in studying details of Tycho's funeral - in particular the ornate clothes in which he was buried: "I'm hoping in the coming year to finish my book about Tycho's burial in Prague and all the archaeological finds and what we've learned, and we also need to finish the conservation of the clothes in which he was buried. We know that it was a very nice dress with a fantastic collar, and we hope to make a reconstruction and a replica of his body so that we can put the figure of Tycho in a museum with his dress, shoes, hair and everything."

Aside from a few fragments stored in laboratories, however, Tycho's remains are now once again safely at rest in their Prague tomb. With a plausible medical explanation of his final days, perhaps the controversy around the life and death of this most extraordinary astronomer will finally fade away - though his reputation will surely live on.



What actually happened

Analyses of Tycho's bones and hair since the 2012 exhumation suggest the great astronomer's sudden decline was just the inevitable consequence of his extravagant lifestyle

A life of excess

Analysis of isotopes – variants of chemical elements that can reveal their origins – in Tycho's remains suggest that he enjoyed a rich diet of meat and fish throughout his life – befitting a high-status nobleman but doing very little for his health.

Obesity

Measurements of Tycho's bones – particularly a telltale ratio of the length of his thigh-bone to the diameter of the marrow core within it – confirm that Tycho would today be classified as obese.

DISH syndrome

Looking at Tycho's spine revealed that he also suffered from a disorder in which the soft tissues around joints near the spine calcify, fusing vertebrae together.

Onset of diabetes

DISH is often associated with other diseases such as type 2 diabetes – high blood sugar and a lack of insulin due to a failure of the pancreas – as is obesity. Untreated diabetes could be associated with the symptoms of Tycho's last days.

Alcoholism

Tycho was known to be a heavy drinker throughout his life, and this could have given rise to an acute condition called alcoholic ketoacidosis that often leads to hospitalisation today.

Final blow

Tycho's final days, however, seem to closely match the symptoms of hyperglycemia – a result of untreated high blood sugar due to diabetes. Even today, hyperglycemia carries a high risk of fatality.

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CHAMELEON THEORY

Testing an alternate method to Einstein's general relativity

Reported by Passant Rabie

A group of scientists has created a computer simulation of the universe in order to test out an alternative theory to Albert Einstein's theory of general relativity. Their study found that galaxies similar to our own Milky Way could still form in the universe with modified laws of gravity, suggesting that the theory of relativity is not the only way to explain gravity's role in the evolution of the universe.

Physicists from Durham University in England created the computer simulations using a leading alternative model for gravity called 'f(R) gravity', also known as 'Chameleon Theory', which alters the behaviour of gravity according to the surrounding environment. The simulations showed that the modified gravity model could still lead to galaxy formation.

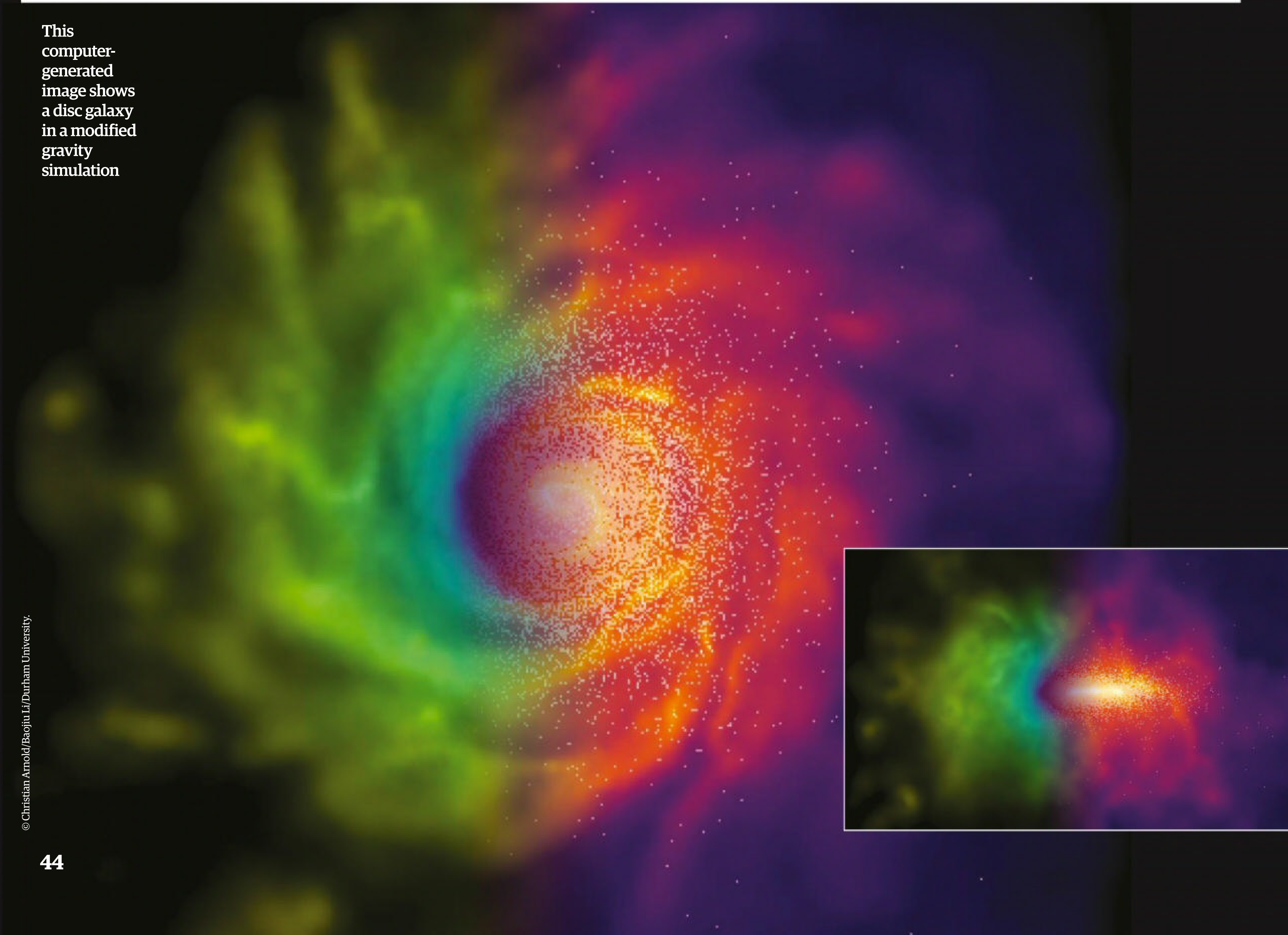
"Modified gravity theories, including Chameleon Theory, had been studied by the community for a while, and a lot of their predictions were known," Baojiu Li, a physicist at the Institute for Computational Cosmology at Durham University, told us. "However, the majority of these previous studies were conducted with a critical simplification - the assumption that the universe contains only dark matter, and no luminous matter."

One of the unanswered questions in cosmology is the reason that the universe is expanding, Li said, and other models have tried to answer that question by introducing an unknown force called dark energy. This constant force in the theory of general relativity can account for the expansion of the universe, but does so by including a vast amount of dark matter that remains unconfirmed.

Scientists believe that around 68 per cent of the universe is made up of dark energy, while dark matter makes up 27 per cent; normal matter, which includes bodies that are visible to us such as planets, stars and galaxies, makes up around five per cent.

"However, alternatives to a cosmological constant, which explain the accelerated expansion by modifying the law of gravity, like f(R)-gravity, are also widely considered, given how little is known about dark energy," Li added.

The study also looked at the effect of modified gravity on supermassive black holes, which eject heat and material that burns away at the gas needed to form stars. The energy emitted from black holes also feeds nuclei found in galaxies, and therefore plays a major role in galaxy formation.



This computer-generated image shows a disc galaxy in a modified gravity simulation

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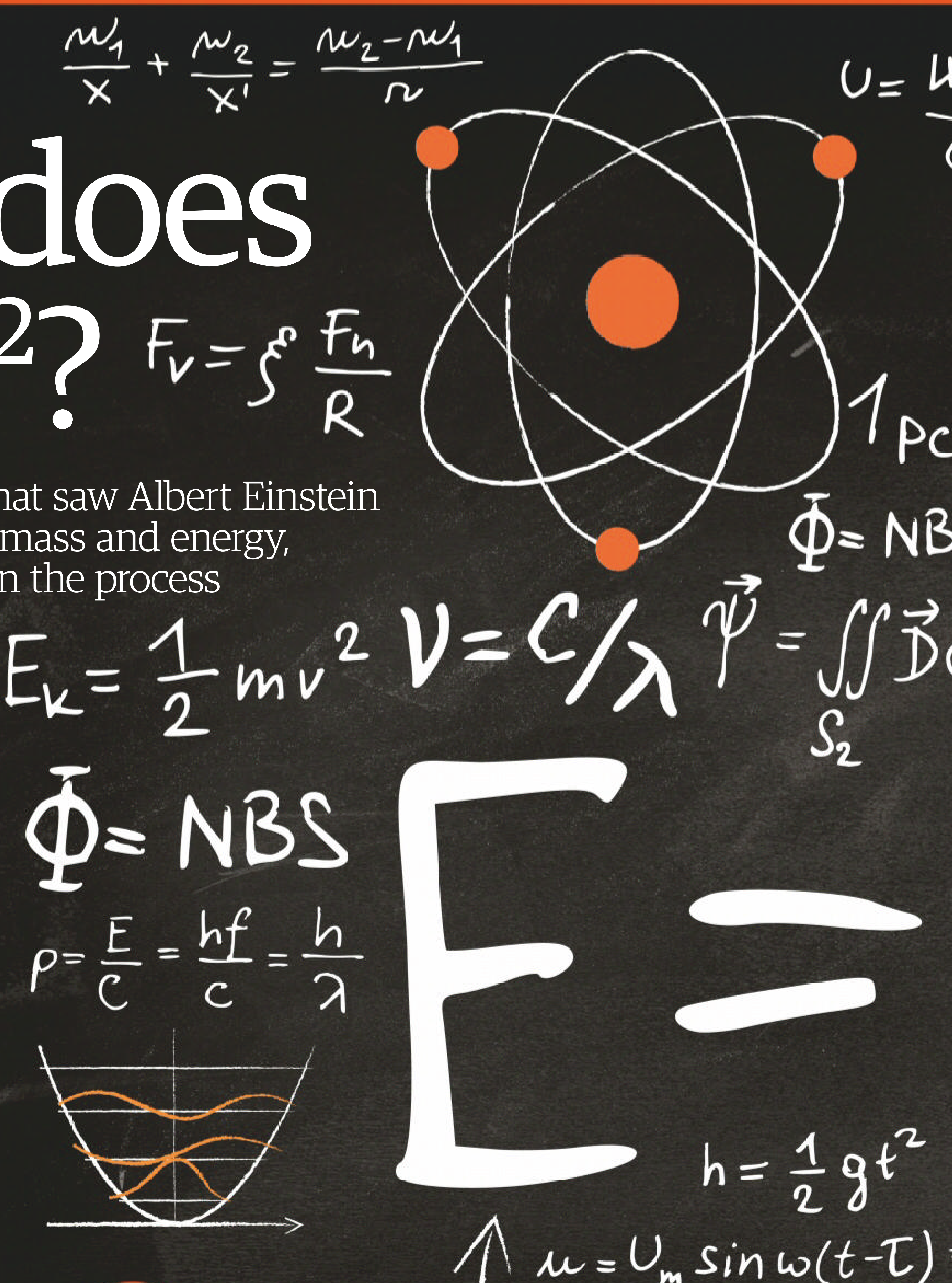
Why does E=Mc²?

It's a familiar equation that saw Albert Einstein bridge the gap between mass and energy, revolutionising physics in the process



$\frac{w_1}{x} + \frac{w_2}{x'} = \frac{w_2 - w_1}{r}$
$F_v = \xi \frac{F_n}{R}$
$E_k = \frac{1}{2} m v^2$
$V = C/\lambda$
$\Phi = NBS$
$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$
E =
$h = \frac{1}{2} g t^2$
$u = U_m \sin \omega(t - \tau)$

One of the most famous equations in the history of science is Albert Einstein's equation, E=mc², published in 1905, the year known as Einstein's 'annus mirabilis'. In this work Einstein established the equivalence between mass and energy, two concepts disconnected until then. In such a simple and beautiful way, the theory of special relativity governing space, time, matter and energy came to be. In the subsequent decade Einstein expanded his theory to include gravity, thereby creating the theory of general relativity. Both theories are essential for the functionality of a lot of modern technology, for instance GPS navigation systems, without which we could not even dream of self-driving cars.

This simple yet fundamental equation involves only three quantities: energy, E; mass, m, and the vacuum speed of light, c. It tells us that mass may be converted into energy, more specifically that a given process involving just a tiny bit of mass may lead to the release of an enormous amount of energy. An example of the process occurring in nature is electron-positron annihilation, where an electron and its antiparticle, the positron, may interact, leading to their disappearance and the appearance of two high-energy gamma-ray photons: production of light from matter. Perhaps more surprising, this equation also implies that it is possible to produce mass from energy. For example, two photons, which are massless, with sufficient energy may interact and create an electron-positron pair: production of matter from light. Another example of this relation between mass and energy is the creation of helium from two hydrogen atoms, and a fraction of the hydrogen mass is radiated into energy in this fusion process. This is the underlying physics that allows stars to shine and remain stable for long periods of time. We can thus witness the effects of E=mc² everyday by noting the light from our Sun and watching the starry sky during the night.

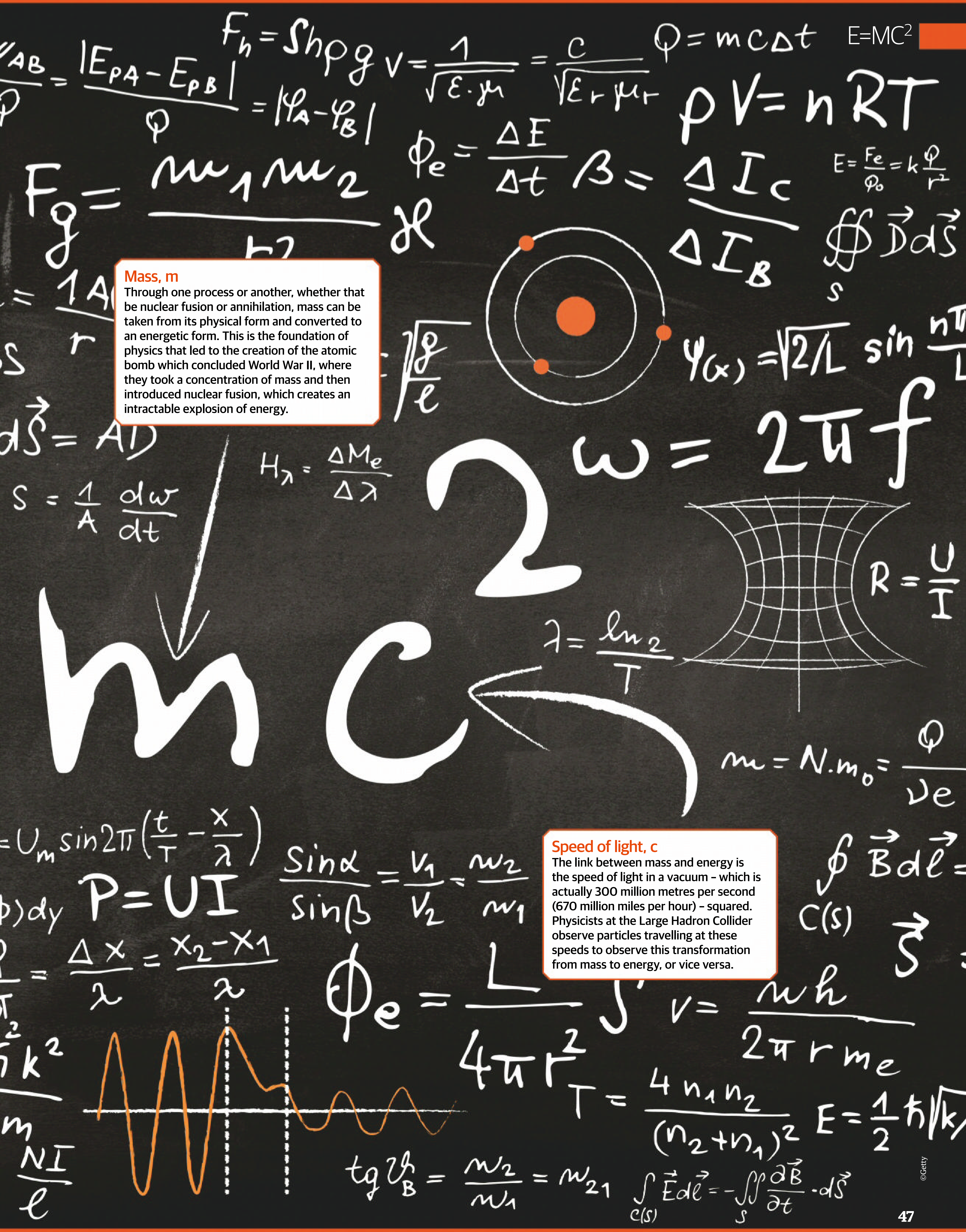
BIO

Dr Alberto Domínguez

Domínguez is an astrophysicist in the High Energy Group (GAE) of the Universidad Complutense de Madrid, Spain. His main area of research is understanding the most energetic regions of the cosmos, particularly gamma rays. But this knowledge of 'energy' stems from the century-old theories of Albert Einstein.

Energy, E

Everything has – or has the potential to be – energy. That is a fact. Even the pen sitting on your desk has energy associated with it, and this is inferred by Einstein's most famous equation. More specifically, a process involving just a tiny bit of mass may lead to the release of an enormous amount of energy given the very large value of the square of the speed of light.



Mass, m
Through one process or another, whether that be nuclear fusion or annihilation, mass can be taken from its physical form and converted to an energetic form. This is the foundation of physics that led to the creation of the atomic bomb which concluded World War II, where they took a concentration of mass and then introduced nuclear fusion, which creates an intractable explosion of energy.

Speed of light, c
The link between mass and energy is the speed of light in a vacuum – which is actually 300 million metres per second (670 million miles per hour) – squared. Physicists at the Large Hadron Collider observe particles travelling at these speeds to observe this transformation from mass to energy, or vice versa.

©Getty

Moon profile

Europa

One of the Solar System's famous ocean worlds is an exciting prospect for further exploration

Europa is one of the four Galilean moons that orbit the Solar System's largest planet, Jupiter. Although Europa is the smallest of its satellite siblings – Io, Callisto and Ganymede, carrying on in that order from smallest to largest – it is certainly the one with the most potential for exciting scientific discovery. Underneath its icy, scarred surface could lie a salty ocean, just like the oceans that make up 71 per cent of the Earth's surface.

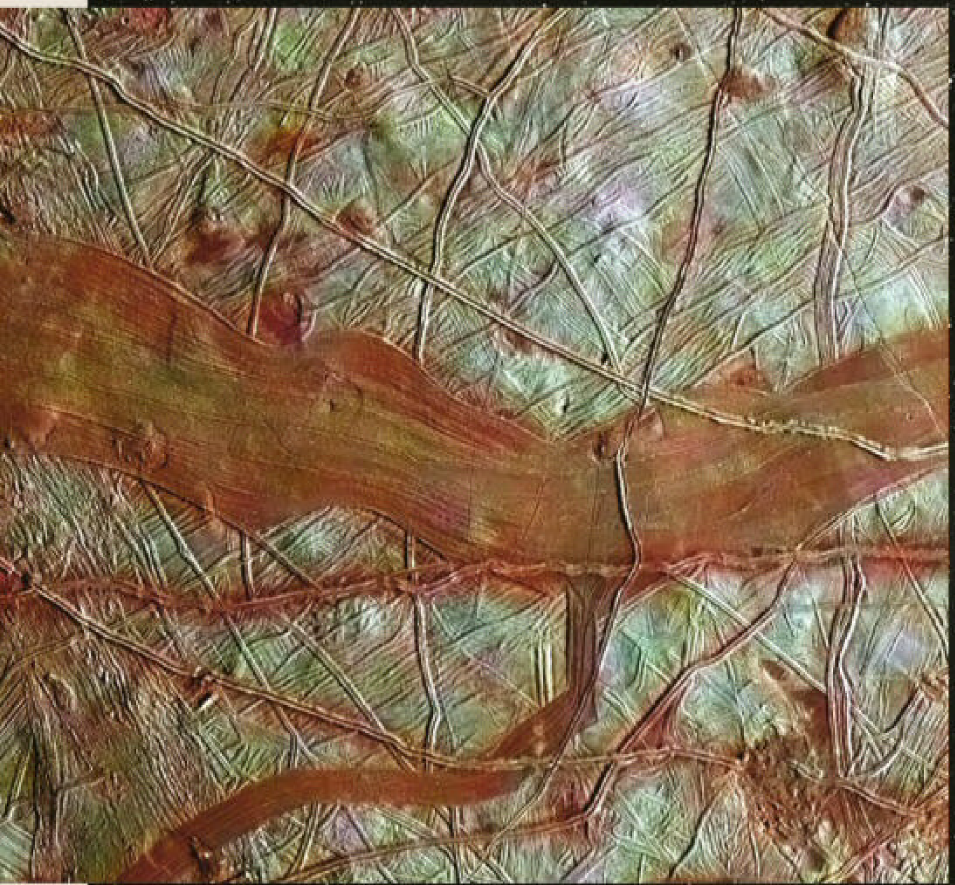
The Galilean moons were discovered in 1610 by Italian astronomer Galileo Galilei, and through the ages astronomers have been fixating their telescopes on the speck of light that orbits Jupiter once every three-and-a-half days. Europa is also tidally locked to Jupiter, meaning that the same face of the moon is pointing at the Jovian giant at all times, much like the Moon and Earth. Another similarity is the two moons' sizes: Europa has an equatorial diameter of 3,100 kilometres (1,940 miles), which is 90 per cent of the Moon's diameter. If you were to replace the Moon with Europa in our sky, to the naked eye they would both seem about the same size. However, Europa would be much brighter on account of its surface ice reflecting 5.5-times more sunlight than the Moon.

> "Underneath its icy, scarred surface could lie a salty ocean"

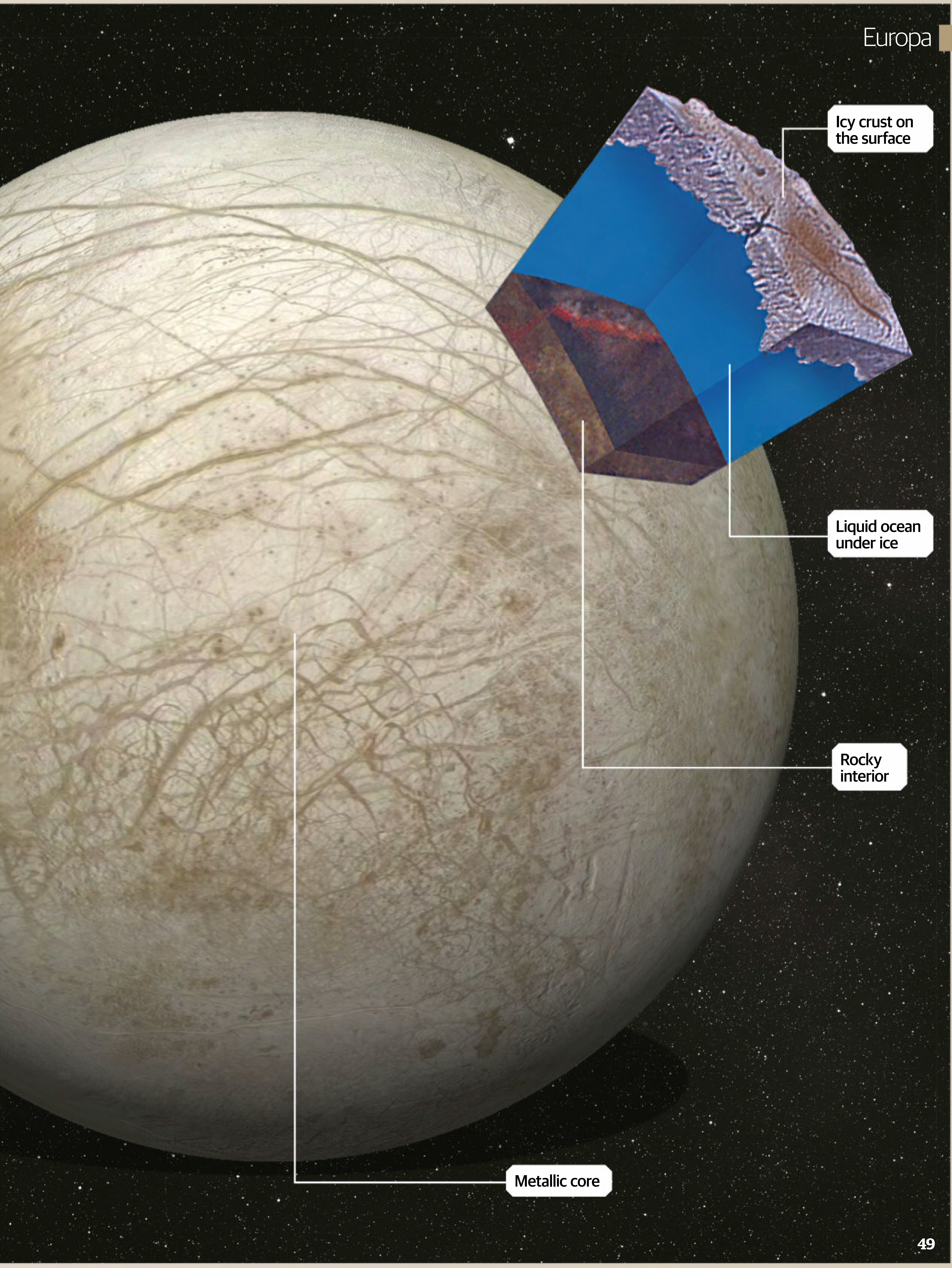
The process behind the creation of Jupiter's largest moons is still hotly debated, but astronomers largely agree that they formed from leftover debris from the formation of Jupiter roughly 4.5 billion years ago. Fast-forward to today and Europa is a water-ice ball with fractures criss-crossing all over the surface. The number of craters currently found all over its cracked terrain indicate that the moon is no older than 90 million years old, suggesting there is likely to be some form of surface replenishment that also brings salts and sulphur compounds to the outer layer. Surrounding the icy world is a thin atmosphere, composed of molecular oxygen.

The core is most likely made of iron, surrounded by a tough, rocky mantle. In between that and the icy crust is a suspected body of liquid. Some may wonder how such a small world, so far away from the heat of the Sun, can maintain an ocean of salty water similar to Earth's. The answer is that it's likely due to the grand gravitational effects of Jupiter, pulling and pushing the insides of Europa, causing it to heat up and, in turn, transforming ice into water. This process is known as 'tidal heating', and it can be observed happening with grander effect on fellow moon Io – its interior is heated up to such an extent that volcanoes have popped up.

This tidal heating is what maintains the ocean and provides the energy to replenish the surface via the outburst of plumes or a form of icy plate tectonics. Ever since astronomers became aware of the vitalising interior of Europa, they have pieced together that it has the fundamental building blocks for life to exist: liquid water, chemical compounds for consumption and an energy source. For this reason especially, planetary scientists are excited to return to the Galilean moon. There is a high chance that life could exist in this part of the Solar System, even if it's just in the form of simple microbes.



This shows almost-pure water ice, shown in white, broken up by contaminated water ice, shown in red



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What's been happening at Europa?

Table salt found sprinkled on the surface

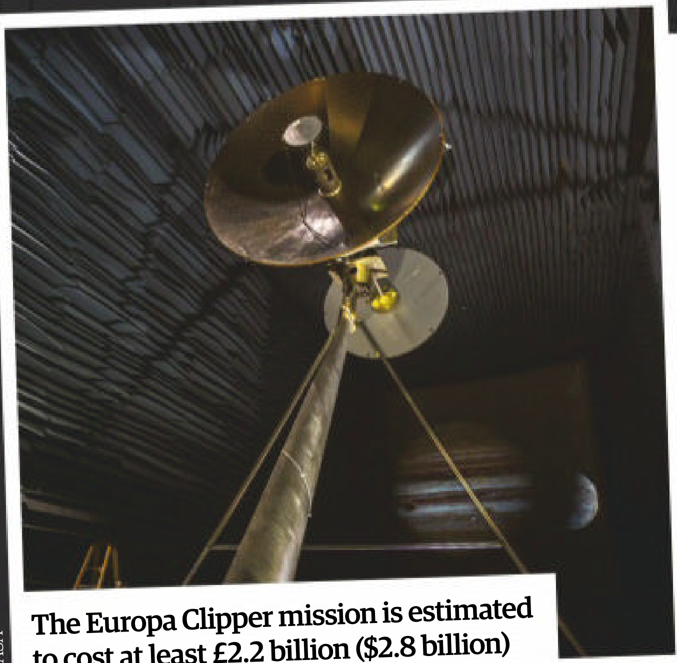
Europa has had visitors in the past, notably NASA's Voyager and Galileo spacecraft. On their flybys of the moon, analyses showed that the icy crust consisted of water ice and a substance originally thought to be magnesium sulphate. After recently revisiting the surface using the W. M. Keck Observatory based in Hawaii and the Hubble Space Telescope, astronomers now know that it wasn't magnesium sulphate and was actually sodium chloride – more commonly known as table salt.

As Voyager and Galileo had only an infrared spectrometer to work with, they couldn't see what was hiding in the visible light spectrum. Keck and Hubble were able to unveil the hidden secret. "We thought that we might be seeing sodium chlorides, but they are essentially featureless in an infrared spectrum," says Mike Brown, the Richard and Barbara Rosenberg professor of planetary astronomy at Caltech in Pasadena, California.

It was some laboratory tests by Kevin Hand at NASA's Jet Propulsion Laboratory, also in Pasadena, that revealed that irradiating ocean salts under Europa-like conditions exhibit distinct features and a yellowish colour – table salt exhibits this colour on the surface of Europa, confirming its presence.

Tara Regio is a section of Europa that flaunts the yellowish signature of table salt

© NASA/JPL



The Europa Clipper mission is estimated to cost at least £2.2 billion ($2.8 billion)

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Setbacks for Europa's next explorer

NASA has its sights set on sending two very ambitious missions to Europa, one of which is due to launch in 2023. Unfortunately the Europa Clipper mission, an orbiter that will spend about three years at the moon, and the proceeding Europa Lander mission seem to have come under scrutiny after a nine-month investigation concluded that there are serious issues that need to be addressed in order to satisfy both NASA and the United States Congress.

"Our audit found that despite robust early stage funding, NASA's aggressive development schedule, a stringent conflict-of-interest process during instrument selection, an insufficient evaluation of cost and schedule estimates and technical workforce shortages have increased instrument integration challenges and development risks for the Clipper mission," John Schultz, a management analyst at the Office of Inspector General, said in a statement.

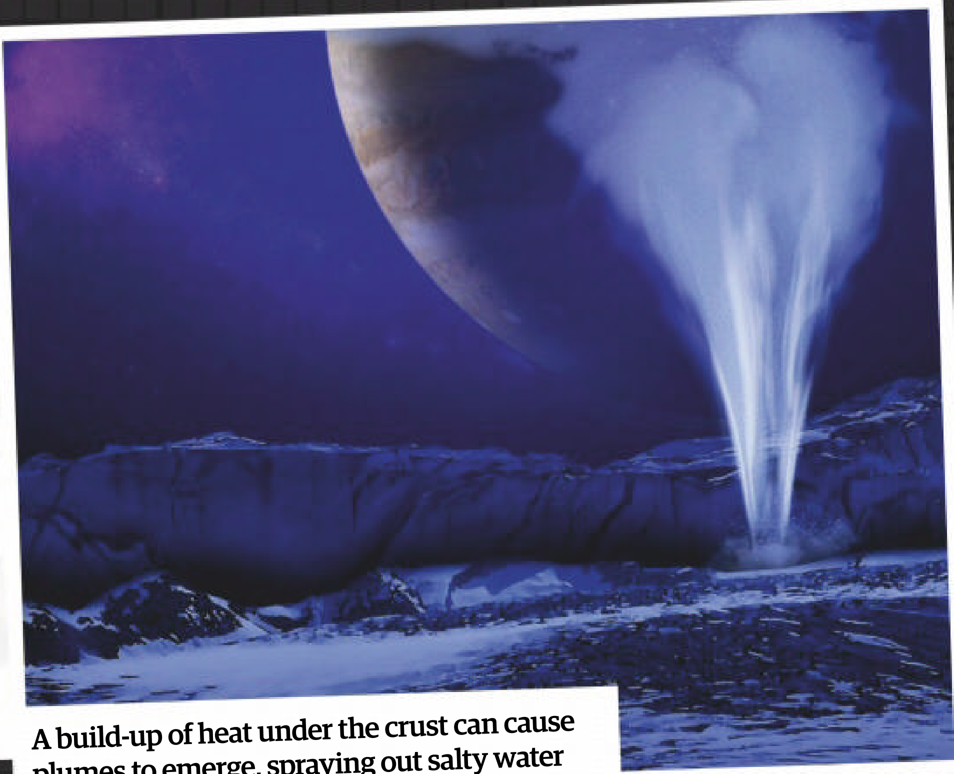
After finding these conflicts of interest and issues in the budget, the investigation team have concluded that ten changes should be made in order to get the project back on track, including altering the overall staffing regime, rescheduling milestones and making sure that any estimates be made in accordance with other projects.

> "We searched through the available Galileo thermal data at the locations proposed as the sites of potential plumes"

Struggling to find the plumes

Europa is a moon that shares many similarities with Saturn's moon Enceladus – both are icy worlds that exhibit signs of a subsurface ocean that could harbour potential life. One major difference though is that Enceladus has been studied much more thoroughly, courtesy of NASA's Cassini mission. In this close-up analysis Cassini detected plumes of material emerging from the surface of Enceladus, along with a distinct temperature spike in the data to match. However, this doesn't appear to be the same for Europa.

"We searched through the available Galileo thermal data at the locations proposed as the sites of potential plumes. Reanalysis of temperature data from the Galileo mission does not show anything special in the locations where plumes have possibly been observed. There are no hotspot signatures at either of the sites," says Julie Rathbun, a senior scientist at the Planetary Science Institute. "This is surprising because the Enceladus plumes have a clear thermal signature at their site of origin, so this suggests that either the Europa plumes are very different, or the plumes are only occasional, that they don't exist or that their thermal signature is too small to have been detected by current data."



A build-up of heat under the crust can cause plumes to emerge, spraying out salty water

© NASA/ESA

The past and future of exploration

Being part of the Jovian system has its benefits in terms of exploration. Although Europa hasn't had the same close inspection as Enceladus, many spacecraft have made a flying visit of the moon as they use Jupiter's enormous mass to provide a 'gravity assist' – when a spacecraft uses a planet's mass to slingshot it to a faster speed.

The first of these visits began with NASA's Pioneer 10 and 11 in 1973 and 1974 respectively. Afterwards came the two Voyager spacecraft in 1979, sending back pictures of Europa's icy surface in stunning resolution.

This began speculation that the moon had a subsurface ocean, gathering traction when NASA's Galileo spacecraft spent eight years at the Jovian system, starting in 1995. This long-duration study revealed a host of exciting new discoveries about Europa and its fellow moons. The last spacecraft to visit Europa was NASA's New Horizons in 2007 when it tested its equipment at the Jovian system on the way to Pluto.

The future is very exciting for the Galilean moons. Two major space exploration organisations, the European Space Agency (ESA) and NASA, are looking to visit. Due to launch in June 2022 is the ESA's JUpiter ICy moons Explorer (JUICE), which will head to the system in order to study Ganymede, Callisto and Europa. The following year – assuming there are no delays from the aforementioned investigation – NASA will launch its Europa Clipper, solely focused on studying Europa.

After much discussion the Europa Clipper team decided that, due to Jupiter's radiation, it would be best to put the orbiter in an elliptical orbit that makes 45 close flybys over the course of roughly three years. In a separate mission in around 2025, there will be a Europa Lander that will complement the Europa Clipper mission.

Europa is one of the most reflective objects in the Solar System because of its icy surface

NASA's timeline of Europa visitors

- **Date:** 3 December 1973
  Spacecraft: Pioneer 10
- **Date:** 3 December 1974
  Spacecraft: Pioneer 11
- **Date:** 5 March 1979
  Spacecraft: Voyager 1
- **Date:** 9 July 1979
  Spacecraft: Voyager 2
- **Date:** 8 December 1995 to 21 September 2003
  Spacecraft: Galileo
- **Date:** 28 February 2007
  Spacecraft: New Horizons

Europa facts

671,100 km

Europa orbits Jupiter at a distance of 671,100 kilometres (417,000 miles), almost double that of the Earth-Moon distance.

Europa is the smoothest object in the Solar System, lacking more craters and mountains than any other object.

Hydrothermal vents could exist on the seabed of Europa, similar to what is seen on the floor of Earth's oceans – a region where extremophiles thrive.

Europa is stuck in an orbital resonance with two fellow Galilean moons; for every orbit Ganymede completes, Europa does two and Io completes four.

All of Jupiter's moons are named after the lovers of Zeus from Greek mythology; Europa was the queen of Crete.

Europa's surface temperature at the equator never reaches higher than -160 degrees Celsius (-260 degrees Fahrenheit).

-160°

The cracks on the surface of the moon are thought to be from the constant movement of the subsurface sea when it gets too close to Jupiter.

© NASA;

THE WEIRDEST STAR IN THE UNIVERSE

Tabby's Star made headlines with its mysterious behaviour, but is it still the strangest?

Reported by Andrew May

There are at least 100 billion stars in our galaxy, and some of them are pretty weird in appearance or behaviour. But only a limited number of natural processes are at work, so nature has a way of repeating itself. For a star to be *uniquely* weird, there would have to be something artificial about it – the product, not of nature, but of an alien civilisation. That's not to say the star itself has to be artificial, just that our view of it is somehow altered as a consequence of alien technology. If we could find something like that, it would be the astronomical discovery of the millennium – and there are a couple of good candidates already.

Is it really possible that alien engineers could build an artificial structure around a star that's so enormous it would affect the way the star looks to us? The first person to give serious consideration to such an alien megastructure was the British-born physicist Freeman Dyson, way back in 1960. He imagined that a super-advanced civilisation, rather than venturing into the depths of interstellar space, might choose to stay in its own planetary system and expand its territory there. It might do this by redistributing planetary material into a vast spherical shell around their star – not a solid shell, but a dense swarm of orbiting bodies. The resulting 'Dyson sphere' would provide living space for an enormously

© Nicholas Forder

expanded population at just the right distance from the star, while at the same time – by capturing a significant fraction of the star's emitted light – yielding a virtually unlimited supply of energy.

So it's not beyond the bounds of possibility that a sufficiently advanced civilisation might create a megastructure. The next question is whether we could detect such a thing with our current astronomical instruments. This ties into the relatively new astronomical concept of 'technosignatures' – observable indications of advanced extraterrestrial civilisations. It encompasses active emissions like radio waves and laser communications, as well as more indirect evidence that might indicate the presence of things like Dyson spheres. Dyson himself, picturing a more-or-less complete sphere enveloping a star, realised that it would absorb most of the light from the star and reradiate the waste energy as heat – as infrared radiation. So he suggested searching for stars which produce an unnatural amount of infrared compared to visible light.

On the other hand, what if the megastructure is an incomplete sphere, or some other shape such as a ring? This question was thought through by French astronomer Luc Arnold in 2005, and the results written up in a paper he called *Transit Light-Curve Signatures of Artificial Objects*. Arnold drew an analogy with one of the techniques astronomers use to find planets around other stars, known as the transit method. It's a method that received a boost a few years after Arnold's paper, when NASA launched its planet-hunting Kepler spacecraft, which applied the transit method on an industrial scale for almost a decade between 2009 and 2018. The basic idea is simple enough: when a planet transits in front of its parent star, we see a slight dimming of the star's light curve.

The beauty of this technique lies in the fact that the dimming effect produced by a planet is well understood scientifically. Planets move in clearly defined orbits, which means the dimming occurs at regularly spaced intervals. The physics of orbits is well known, so it's easy to work out the planet's distance from the star based on the timing of its orbit. As for the shape and depth of the dips, which should be essentially the same on each orbit – these can tell us the size of the planet. But, as Arnold pointed out in 2005, none of this will be true for a complex, artificial megastructure. If we observe a star with transit-like dips that can't easily be explained in terms of a planet – that's when an alien engineering project becomes a distinct possibility. That's exactly what happened in the case of the star labelled KIC 8462852 in the Kepler catalogue.

The results were first reported in September 2015 in a paper that came out of a citizen science initiative called Planet Hunters. The coordinator of that initiative, and the lead author on the paper, was Tabetha Boyajian – a fact that resulted in KIC 8462852 acquiring the much nicer nickname of Tabby's Star.

There were two very odd things about Tabby's Star's light curve. The dips in it – presumably caused by something transiting between the star and us – occurred at random times, not at the regular intervals that would be expected in the case of an ordinary planet. And those dips were huge, representing a dimming of the star's light by as much as 22 per cent. For comparison, a large, Jupiter-sized planet would only cause a dimming of 1 per cent.

That first paper put forward a number of possible explanations for the large, irregular dimming, ranging from a massive cloud of debris from a planetary collision to a huge swarm of comets. It was left for a follow-up paper the next month by a research group from Penn State University led by Jason Wright, to broach the topic of alien megastructures. Once made, however, the speed with which that suggestion was snapped up by the mainstream media was eye-watering. Throughout October 2015 the press was abuzz with attention-grabbing headlines about the newly discovered 'alien megastructure star' in every imaginable news outlet, from *The Daily Express* to *The Guardian*. Wright was quoted in the latter as saying: "Aliens should always be the very last hypothesis you

© ioerror

Which star is the weirdest?

By comparison, HD 139139 may just pip Tabby's Star to the title

Why is it weird?

Tabby's Star's light curve shows very deep, irregular dips, while HD 139139's are less deep, more planet-like and just as random. Both observations were unexpected.

Weight of evidence

Tabby's Star has been the subject of numerous independent studies, but to date only one study has focused on HD 139139.

Could it be an alien megastructure?

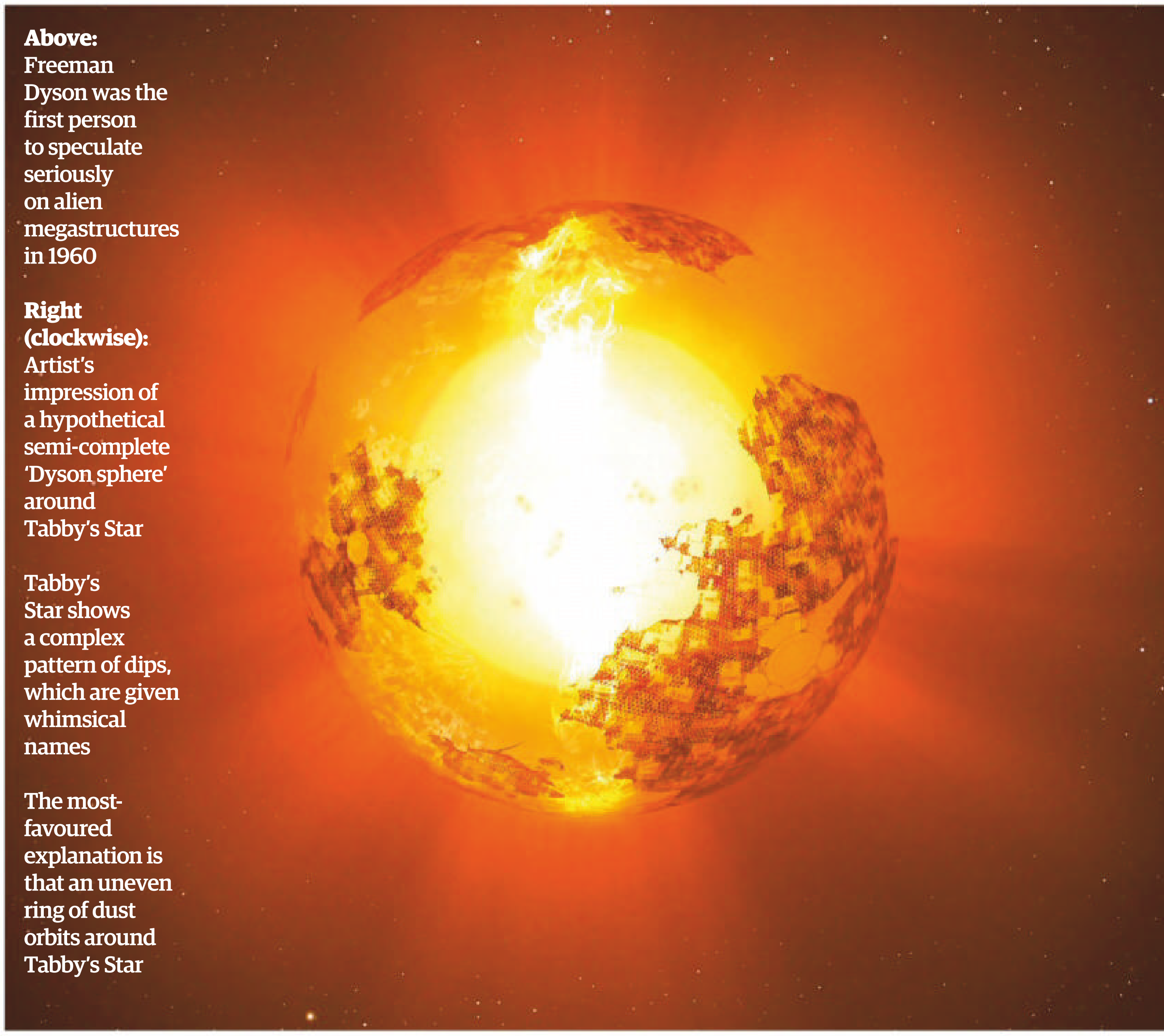
Whatever is orbiting Tabby's Star, it probably isn't a large solid object. But HD 139139's random dips do look like they come from something solid.

What other explanations are there?

Several different theories have been put forward that might explain Tabby's Star, but the behaviour of HD 139139 remains a mystery.

Scientific consensus

Astronomers seem to be converging on the idea of a dust ring around Tabby's Star – but there's no consensus yet on HD 139139.


© Science Photo Library

Above: Freeman Dyson was the first person to speculate seriously on alien megastructures in 1960

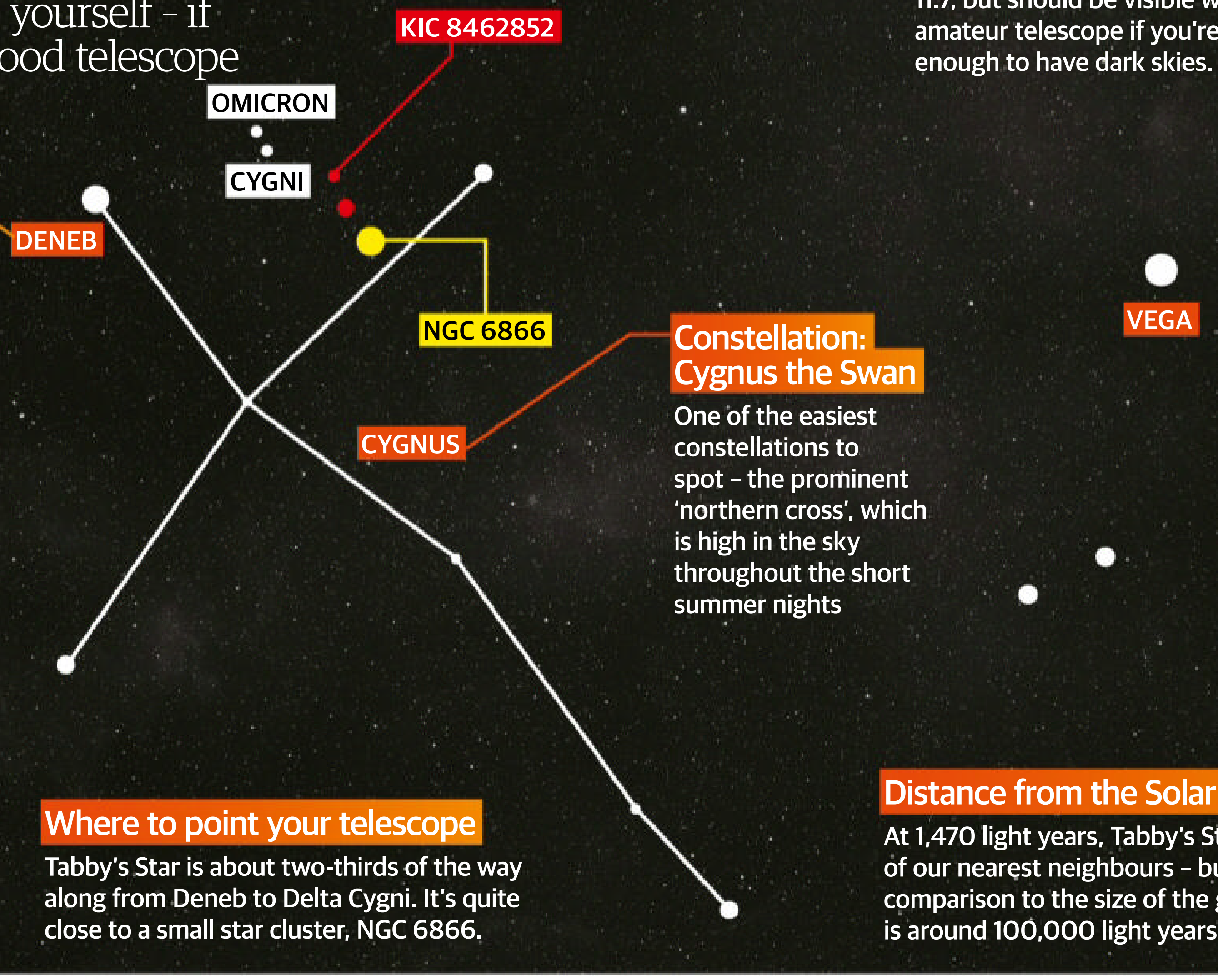
Right (clockwise): Artist's impression of a hypothetical semi-complete 'Dyson sphere' around Tabby's Star

Tabby's Star shows a complex pattern of dips, which are given whimsical names

The most-favoured explanation is that an uneven ring of dust orbits around Tabby's Star

How to find Tabby's Star

See the 'megastructure star' yourself - if you have dark skies and a good telescope



Landmark: Deneb

This is the brightest star in Cygnus, at the tail end of the Swan. To its east is Delta Cygni, marking one wing tip.

What to look for

Tabby's Star is faint at magnitude 11.7, but should be visible with a good amateur telescope if you're lucky enough to have dark skies.

Constellation: Cygnus the Swan

One of the easiest constellations to spot - the prominent 'northern cross', which is high in the sky throughout the short summer nights

Physical characteristics

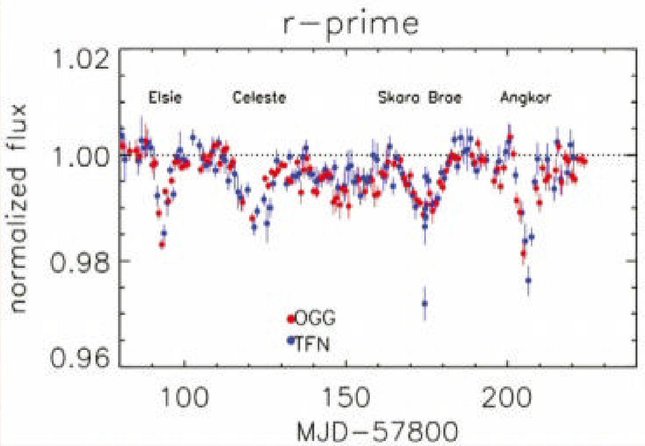
Tabby's Star is a main sequence star like the Sun, but F-type rather than G-type - making it about 40 per cent more massive and a thousand degrees hotter.

Where to point your telescope

Tabby's Star is about two-thirds of the way along from Deneb to Delta Cygni. It's quite close to a small star cluster, NGC 6866.

Distance from the Solar System

At 1,470 light years, Tabby's Star isn't one of our nearest neighbours - but it's close in comparison to the size of the galaxy, which is around 100,000 light years across.



© NASA

> "To me, it makes far more sense that this system is some previously unknown natural phenomenon" **Hugh Osborn**

consider, but this looked like something you would expect an alien civilisation to build."

As well as exciting the media, the hint of an alien megastructure galvanised the Search for Extraterrestrial Intelligence (SETI) community. Follow-up searches were instigated to look for any other technosignatures that might be emanating from Tabby's Star. The searches were unsuccessful - but that had been the realistic expectation all along. As Doug Vakoch of the SETI Institute explained at the time: "Our assumption is that there's going to be a natural explanation for this, we just haven't gotten clever enough to find it."

By the end of 2017 that 'natural explanation' for the mysterious behaviour of Tabby's Star was becoming clearer. The dimming was found to be less pronounced at the infrared end of the spectrum than at the ultraviolet end. That's exactly what astronomers would expect to see if the dimming was caused by a cloud of tiny dust particles - but not from an alien megastructure. As Boyajian explained: "If a solid, opaque object like a megastructure was passing in front of the star, it would block out light equally at all colours. This is contrary to what we observe."

In view of this, the scientific consensus is now veering towards the idea that the peculiar light curve, with its deep, randomly occurring dips, is produced by an uneven ring of dust circling the star. That still leaves a mystery, though, because the only stars normally observed with large amounts of dust in their vicinity are very young ones. Tabby's Star, on the other hand, is a mature main sequence star, somewhat larger and hotter than the Sun. Astronomers would have expected that any dust that once circled it would have condensed into planets long ago - just as happened here in the Solar System. One possibility - though no more than a hypothesis at this stage - is that two of those planets collided with each other in the recent past, shattering themselves into a cloud of dusty debris that's responsible for the dimmings we see.

Even if Tabby's Star turns out to be something other than an alien megastructure, the argument that says such things might exist - and that we could detect them through anomalous light curves - remains valid. As astronomers continue to scour through Kepler data - and yet more data is gathered by its successor, the Transiting Exoplanet Survey Satellite (TESS) - another megastructure candidate might crop up at any moment. In June 2019, that's exactly what happened.

This one hasn't got a nice, friendly nickname yet, but its official designation - HD 139139, with

Investigating Tabby's Star

With the tantalising suggestion of a megastructure, astronomers have searched the stellar object for other technosignatures

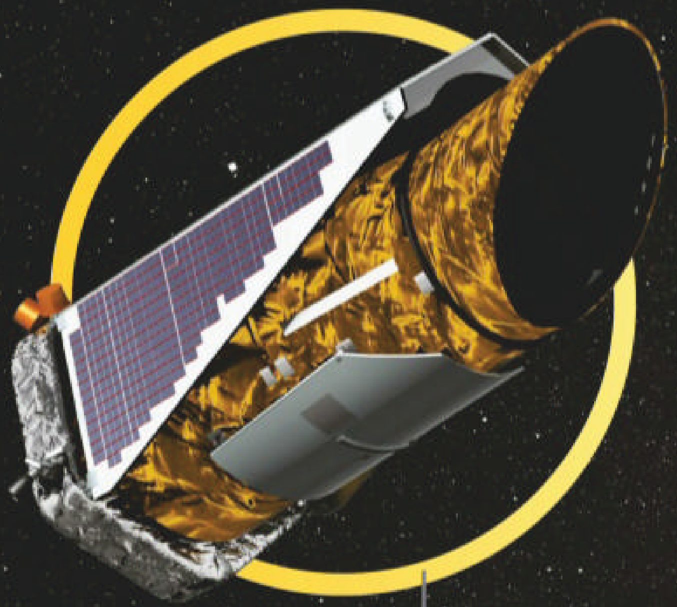
Allen Telescope Array

This is an array of 42 radio telescope dishes in California, operated by the SETI Institute, with the aim of detecting signals from extraterrestrial civilisations. Soon after the Kepler results were published in 2015, it was pointed at Tabby's Star.

What the mission discovered

Over a three-week period the telescope array was focused exclusively on Tabby's Star. It scoured a wide range of frequencies, but failed to discover any artificial signals.

©Getty



The Kepler Space Telescope

Launched by NASA in 2009, Kepler spent almost ten years measuring light curves of hundreds of thousands of stars in search of planetary systems. It discovered some genuinely peculiar light curves, too – none more so than Tabby's Star.

What the mission discovered

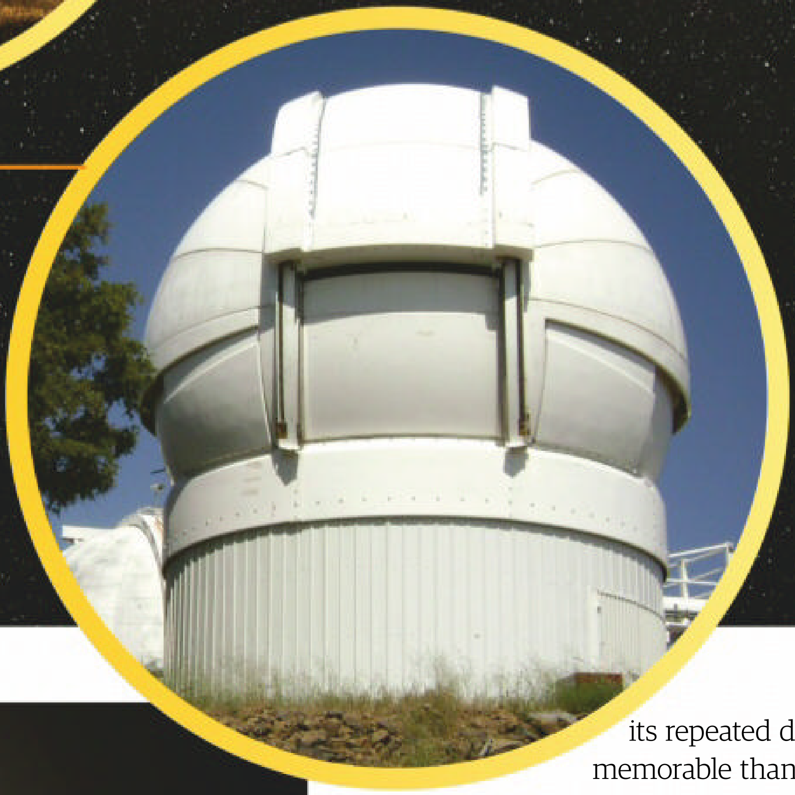
Kepler found deep dips in the light curve, apparently caused by periodic obscuration – but close analysis suggests this is caused by a dust cloud rather than a large solid object.

Automated Planet Finder

This is a large optical telescope at the Lick Observatory in California which is used, among other things, by the 'Breakthrough Listen' project to search for laser signals that might emanate from an advanced extraterrestrial civilisation.

What the mission discovered

The telescope was used to look for possible laser emissions from the vicinity of Tabby's Star in 2018. However, nothing was found that appeared to be of artificial origin.



Below: A less exotic, but more likely explanation for the dimming is a swarm of comets

©NASA

its repeated digits – is more memorable than most. It's around 350 light years away in the constellation Libra, and rather than being a single star it's a binary system, made up of a Sun-like G-type star accompanied by a much smaller red dwarf star. Its light curve was measured by a team led by Andrew Vanderburg from the University of Texas at Austin, who said of it: "We've never seen anything like this in Kepler, and Kepler's looked at 500,000 stars."

The team found no fewer than 28 transits over a three-month period from 23 August to 20 November 2017. These aren't deep dips like those of Tabby's Star – they're the kind that might be produced by an ordinary planet just slightly larger than the Earth. The dips are remarkably consistent in size and shape, too, suggesting that they could all have been produced by the same object. There's a catch, though – the dips don't have the clockwork periodicity you'd expect from a planet. As the researchers put it: "The unusual aspect of these dips is that they exhibit no periodicity, and their arrival

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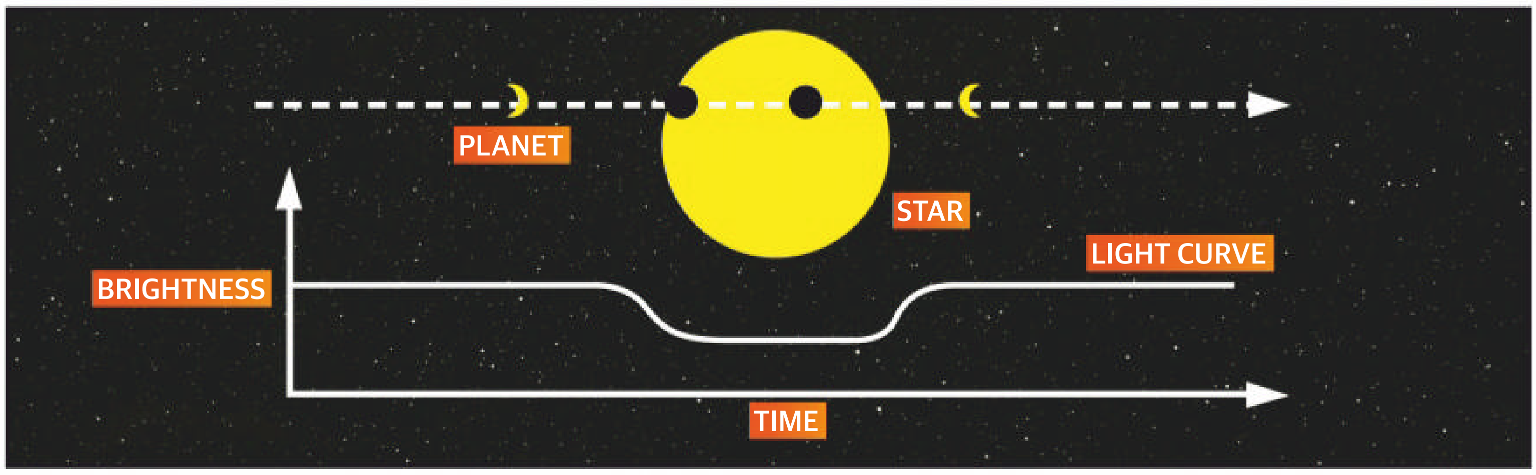
Below: A megastructure could also be a 'ring world' around a star, rather than a sphere



times could just as well have been produced by a random number generator."

The extreme consistency of the dips - in size and shape if not in timing - means that a dust ring is unlikely to be the culprit. Instead they appear to be produced by something large and solid, but it's unclear exactly what. The short duration of the dips mean the objects are travelling quickly, and hence in relatively tight orbits. The observations could be explained if there are a lot of planets, all roughly the same size, travelling on similar but slightly different orbits - but that hardly seems likely. On the other hand, 'multiple similar-sized objects' does sound a lot like a Dyson sphere in the making.

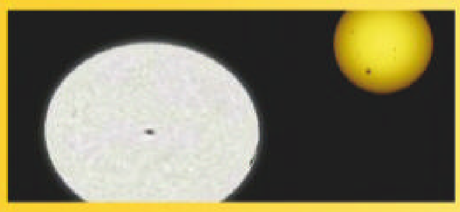
It's an easy conclusion to jump to. As Vanderburg points out: "When people in our community hear about something like this, the running joke is it might be aliens." Yet HD 139139 is as good a contender as anything astronomers have seen to date. As Hugh Osborn, a specialist in transits at the Marseille Laboratory of Astrophysics, said: "The coherent dips in this system look more like solid structures than the incoherent wandering of flux during the eclipses of Tabby's Star." Nevertheless, he remains sceptical of the alien explanation: "To me, it makes far more sense that this system is some previously unknown natural phenomenon."

Just what that 'natural phenomenon' is remains to be seen. One possibility, favoured by Osborn, is that the HD 139139 system contains at least two other stars in addition to the two that can be seen. The extreme complexity of a quadruple system might account for the seemingly random dips that are observed.

Vanderburg agrees that HD 139139 is unlikely to be an alien megastructure: "In astronomy we have a long history of not understanding something, thinking it's aliens, and later finding out it's something else. The odds are pretty good that it's going to be another one of those."

But astronomers have only turned their attention to HD 139139 in the last few months. It's going to require a lot more work to establish just how weird or inexplicable it is. As Boyajian said: "This is one of those systems where it's probably not going to be figured out without more data."

5 other strange stars



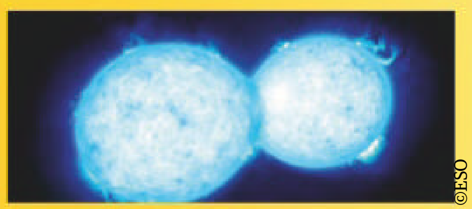
Vega: a squashed star

Vega is one of the brightest stars in the night sky – just 25 light years away and twice the mass of the Sun. Bizarrely it spins so rapidly it's squished out at the equator.

©NASA

Mira: a star with a tail

Mira – Latin for miraculous – was one of the first known variable stars. But it deserves the tag for another reason – UV observations show it has a long, comet-like tail.



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VFTS 352: merging stars

Two stars that are virtually identical twins, orbiting so close to each other that their atmospheres overlap. It's likely they will end up merging into a single star.

©Alamy

AR Scorpii: the white dwarf pulsar

Most pulsars are rotating neutron stars, but this one is a super-dense white dwarf orbited by a larger, but less massive, red dwarf.

©ESA

HD 140283: the aged star

This is the oldest known star, with an estimated age of 13.7 to 15.2 billion years. It's probably the lower estimate, because the age of the universe is only 13.8 billion years!

Manned spacecraft
Astronauts will be transported to and from the CSS by the Shenzhou spacecraft, which roughly translates to 'divine vessel'. This vessel has been taking astronauts to space since 2003.

CHINA'S NEXT SPACE STATION

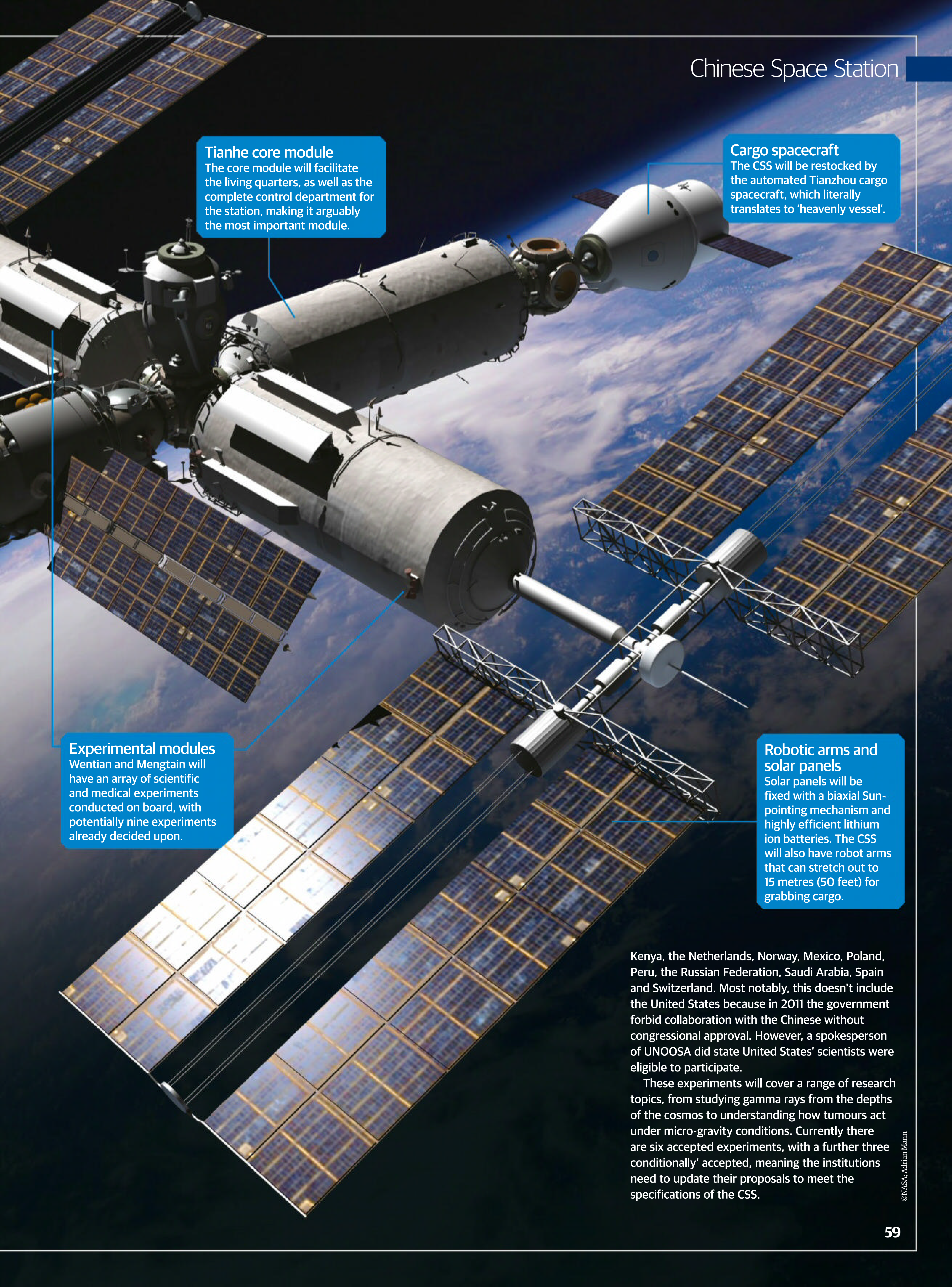
Low-Earth orb construction will hopefully begin in 2020, where it will eventually accommodate three astronauts

There have been many successful space stations throughout the years: NASA's Skylab, Russia's Mir space station and the collaborative International Space Station (ISS), built between the space agencies of Canada, Europe, Japan, Russia and the US. China is another country to have established its presence in low-Earth orbit with space stations Tiangong-1 and Tiangong-2. Now, with 2020 not far off, China is preparing for its next space outpost, which will be known as the Chinese Space Station (CSS).

Tiangong-2 was launched into space in 2016 and dropped out of orbit on 19 July 2019, but this space station was created with the main purpose of testing key technologies for the CSS. The CSS will be around 60 tonnes (130,000 pounds), which is roughly a seventh of the weight of the ISS and roughly half the weight of Russia's Mir space station. This new space station will consist of a core module called 'Tianhe' – meaning 'harmony of the heavens' in Mandarin – two experimental modules, 'Wentain' and 'Mengtian', translating to 'quest for the heavens' and 'dreaming of the heavens' respectively, a cargo spacecraft, a manned spacecraft and several solar panels.

The core module is the centrepiece of the space station. The 18-metre (60-foot) long module with a maximum diameter of 4.2 metres (14 feet) will be the first piece of the puzzle launched into space. It will be sent up around 2020 by China's own heavy-duty rocket, the Long March 5. However, this is dependant on how test flights of the rocket go in late 2019. If all goes to plan then the core module will reach low-Earth orbit and provide three astronauts with their accommodation suite as well as housing vital navigation, guidance, orientation, power, propulsion and life systems for the entire station.

The two experimental modules will be next, and in June 2019 the United Nations Office for Outer Space Affairs (UNOOSA) and the China Manned Space Agency (CMSA) announced the six winning experiments that will be conducted on board the CSS when construction is finished – in 2022 if all goes to plan. These experiments promote international cooperation as the winning institutions come from all over the globe, with science from Belgium, China, France, Germany, India, Italy, Japan,



Tianhe core module
The core module will facilitate the living quarters, as well as the complete control department for the station, making it arguably the most important module.

Cargo spacecraft
The CSS will be restocked by the automated Tianzhou cargo spacecraft, which literally translates to 'heavenly vessel'.

Experimental modules
Wentian and Mengtain will have an array of scientific and medical experiments conducted on board, with potentially nine experiments already decided upon.

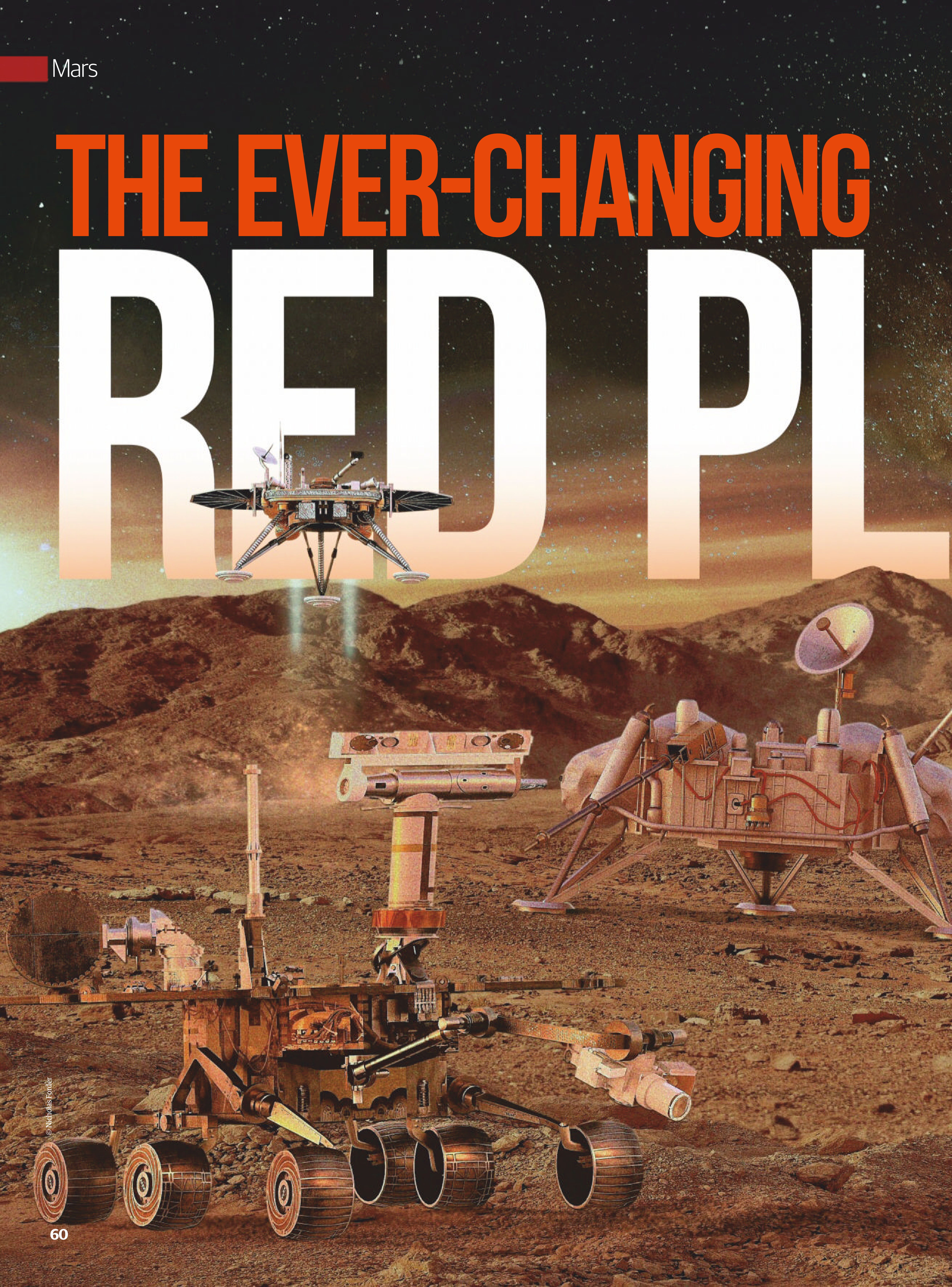
Robotic arms and solar panels
Solar panels will be fixed with a biaxial Sun-pointing mechanism and highly efficient lithium ion batteries. The CSS will also have robot arms that can stretch out to 15 metres (50 feet) for grabbing cargo.

©NASA; Adrian Mann

Kenya, the Netherlands, Norway, Mexico, Poland, Peru, the Russian Federation, Saudi Arabia, Spain and Switzerland. Most notably, this doesn't include the United States because in 2011 the government forbid collaboration with the Chinese without congressional approval. However, a spokesperson of UNOOSA did state United States' scientists were eligible to participate.

These experiments will cover a range of research topics, from studying gamma rays from the depths of the cosmos to understanding how tumours act under micro-gravity conditions. Currently there are six accepted experiments, with a further three conditionally' accepted, meaning the institutions need to update their proposals to meet the specifications of the CSS.

THE EVER-CHANGING RED PL



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Reported by Lee Cavendish

A host of robots have journeyed to the Red Planet, and with each our understanding of Mars has altered

ANET

Before the arrival of NASA's Mariner 4, Mars was thought to be a world similar to Earth – possibly even harbouring alien life. Astronomers suggested that Mars was painted red because that was the colour of its vegetation, and that the streaks along the planet were canals of water – a popular theory proposed by Italian astronomer Giovanni Schiaparelli in 1877.

However, ever since Mariner 4's arrival in 1965, Mars has been studied intensely, and astronomers have figured out that it is actually a barren wasteland. Continued exploration of Mars has shown it to have a deep, interesting history with amazing potential for terraforming. These exciting prospects have all come from the intense, around-the-clock observations of Mars by worldwide organisations.

© NASA/JPL-Caltech; Illustration by Tobias Roetsch

Curiosity has long been on the hunt for signs of life on Mars

MISSING METHANE

Methane is a simple molecule, and astronomers have been scouring Mars for decades in order to find it. This is because the molecule, which consists of one carbon atom with four hydrogen coming off it, is a by-product of microbial life. If microbial life existed there, and astronomers at the time thought it did, then methane would be its calling card.

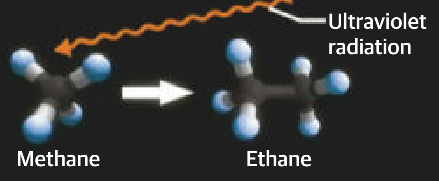
The more astronomers have learnt about Mars and its similarity to Earth billions of years ago, the more they speculated that the planet could have harboured microbes, or even still does. Any methane detection on Mars would hugely encourage this speculation.

Unfortunately, astronomers hit a wall in methane detection. NASA's Curiosity rover has a much more sophisticated instrumentation suite compared to its older siblings, Opportunity and Spirit, but the methane mystery has continued. In June 2019 a 'methane spike' detection was measured, but afterward it sharply decreased, meaning it was likely just a passing plume of methane. Though scientists are still not giving up on the hunt for life by-products, the missing evidence is certainly throwing a spanner in the works in understanding the history of Mars.

DESTRUCTION OF METHANE

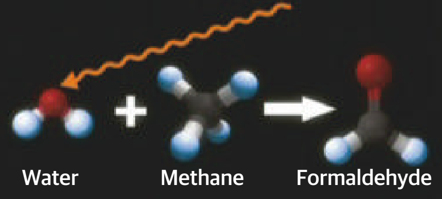
Photochemical reaction

Occurs mainly above 60km (37mi)



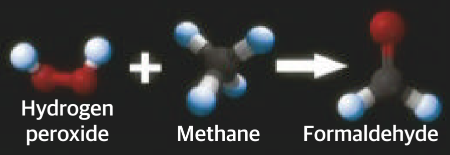
Oxidation

Occurs in Mars' lower atmosphere

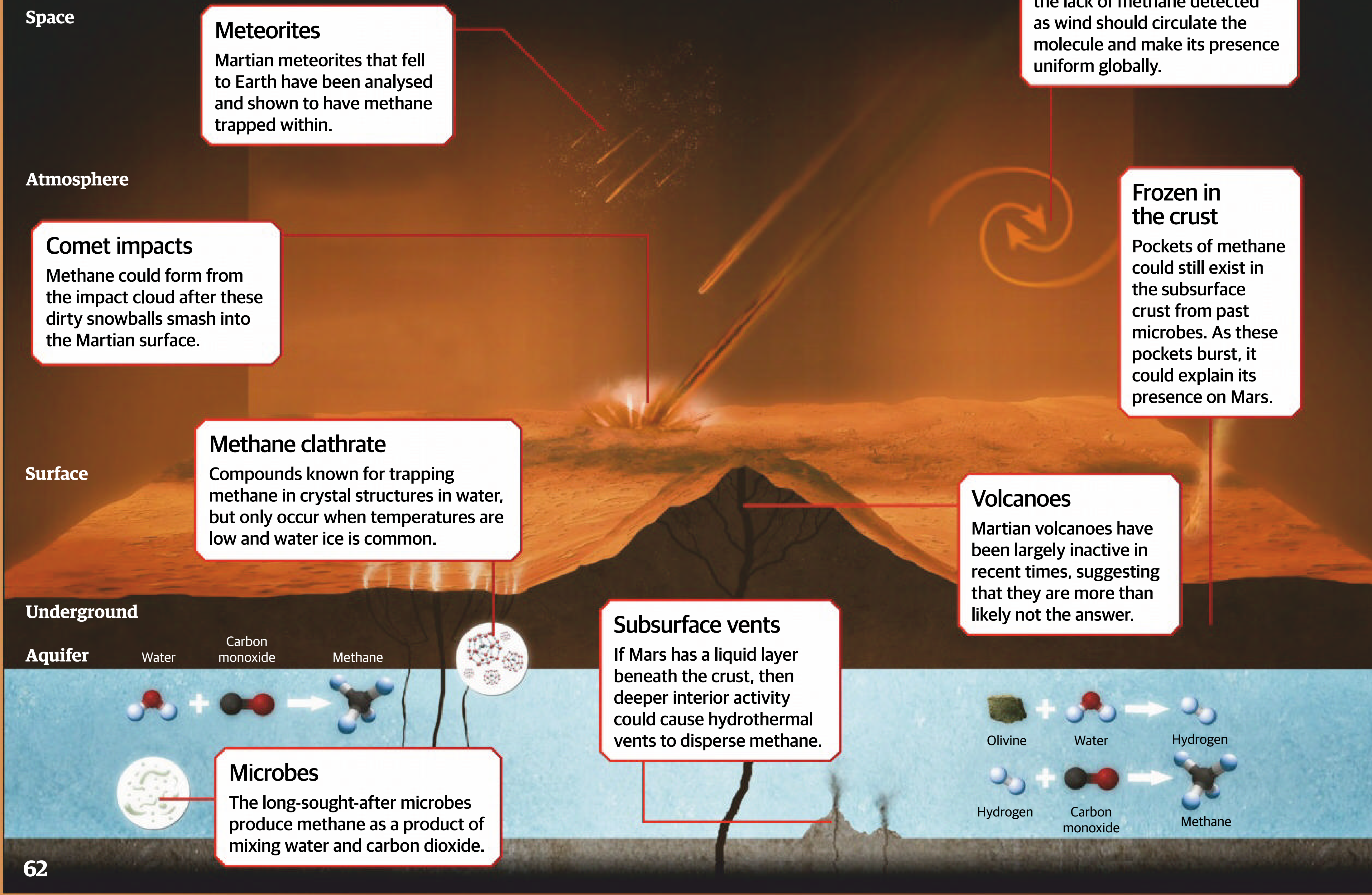


Electrochemical reaction

Driven by dust devils and wind



THE METHANE MYSTERY: DOES IT EXIST OR IS IT JUST HIDING?



Meteorites

Martian meteorites that fell to Earth have been analysed and shown to have methane trapped within.

Comet impacts

Methane could form from the impact cloud after these dirty snowballs smash into the Martian surface.

Methane clathrate

Compounds known for trapping methane in crystal structures in water, but only occur when temperatures are low and water ice is common.

Microbes

The long-sought-after microbes produce methane as a product of mixing water and carbon dioxide.

Subsurface vents

If Mars has a liquid layer beneath the crust, then deeper interior activity could cause hydrothermal vents to disperse methane.

Winds

Astronomers were surprised by the lack of methane detected as wind should circulate the molecule and make its presence uniform globally.

Frozen in the crust

Pockets of methane could still exist in the subsurface crust from past microbes. As these pockets burst, it could explain its presence on Mars.

Volcanoes

Martian volcanoes have been largely inactive in recent times, suggesting that they are more than likely not the answer.

Viking 2 landed on the field of red rocks in the Utopia Plain of Mars

© NASA/JPL

VIKING'S FALSE HOPE

In 1976 the world saw NASA's ambitious Viking mission arrive at Mars. This mission consisted of two identical spacecraft - each consisting of an orbiter and a lander - performing a comprehensive study of Mars both from in orbit and on the surface.

Viking 1 and 2 were masterfully placed into orbit and became the first landers to successfully touch ground and return data. This incredible feat allowed astrobiologists to run the experiments they had on board the lander. With much excitement the astrobiologists waited to see what elusive microbial life there may be on Mars... nothing.

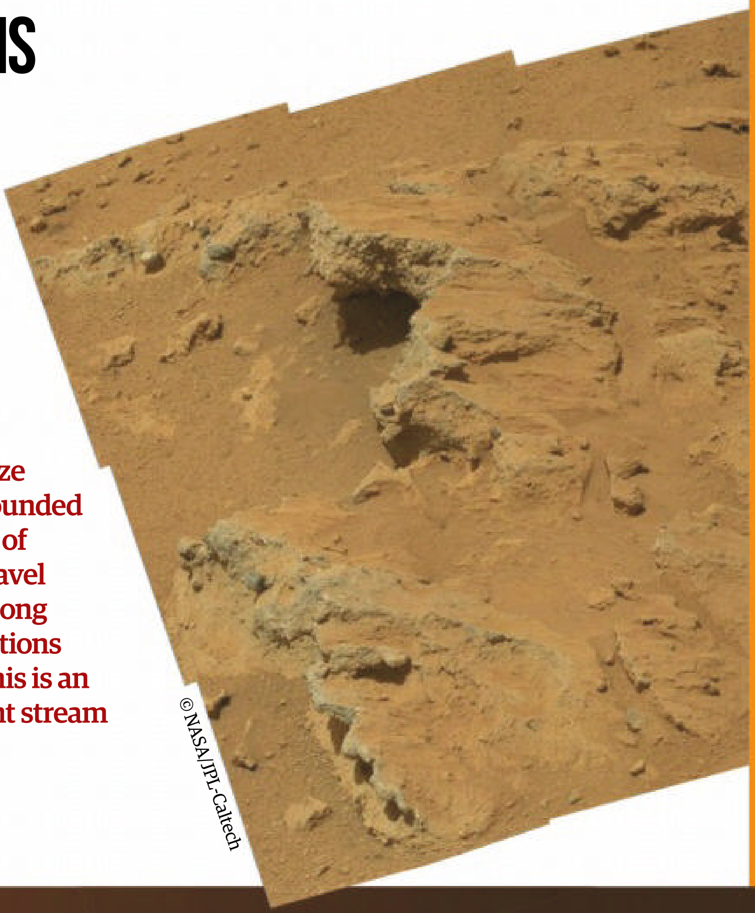
Afterwards chief project scientist Gerald Soffen said the results from the biology tests were "inconclusive", but "yielded some clues to the chemistry of the surface". This made for unfortunate news as this was the first time scientists had searched for life on another planet. However, it did allow scientists and engineers to put their own methods under a microscope and reflect on if their experiments were up to the job. Therefore Viking had long-lasting implications on future missions and our understanding of Mars as more missions came and went.

> "VIKING 1 AND 2 WERE MASTERFULLY PLACED INTO ORBIT AND BECAME THE FIRST LANDERS TO SUCCESSFULLY TOUCH GROUND AND RETURN DATA"

SHATTERING ANCIENT PERCEPTIONS

As eluded to earlier, there were lots of theories about Mars during the late-19th century. Schiaparelli announced that he had spotted canali - meaning 'canals' in English - around the equatorial regions of Mars, and many other astronomers backed him up and even drew maps of Mars illustrating spiderweb-like structures on the surface.

However, the main discovery about Mars by any space probe that has either orbited or landed on the planet is that there are no canals of flowing water. Once upon a time there was, but these 'canals' are actually the remnants of streambeds, which have now been imaged up-close by NASA's revolutionary exploration rovers. In the case of NASA's Curiosity rover, it was able to photograph an ancient streambed which was given the name 'Hottah' after Canada's Northwest Territories.



The size and rounded shape of the gravel are strong indications that this is an ancient stream

© NASA/JPL-Caltech

THE RED PLANET STATISTICS

15 EARTH YEARS

How long NASA's Opportunity rover lasted on Mars

95%

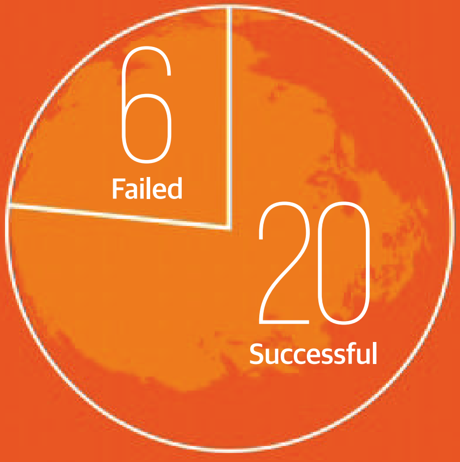
of Mars' atmosphere is carbon dioxide

100X THINNER

Martian atmosphere compared to Earth atmosphere

21KM

How far NASA's Curiosity rover has travelled at the time of writing.



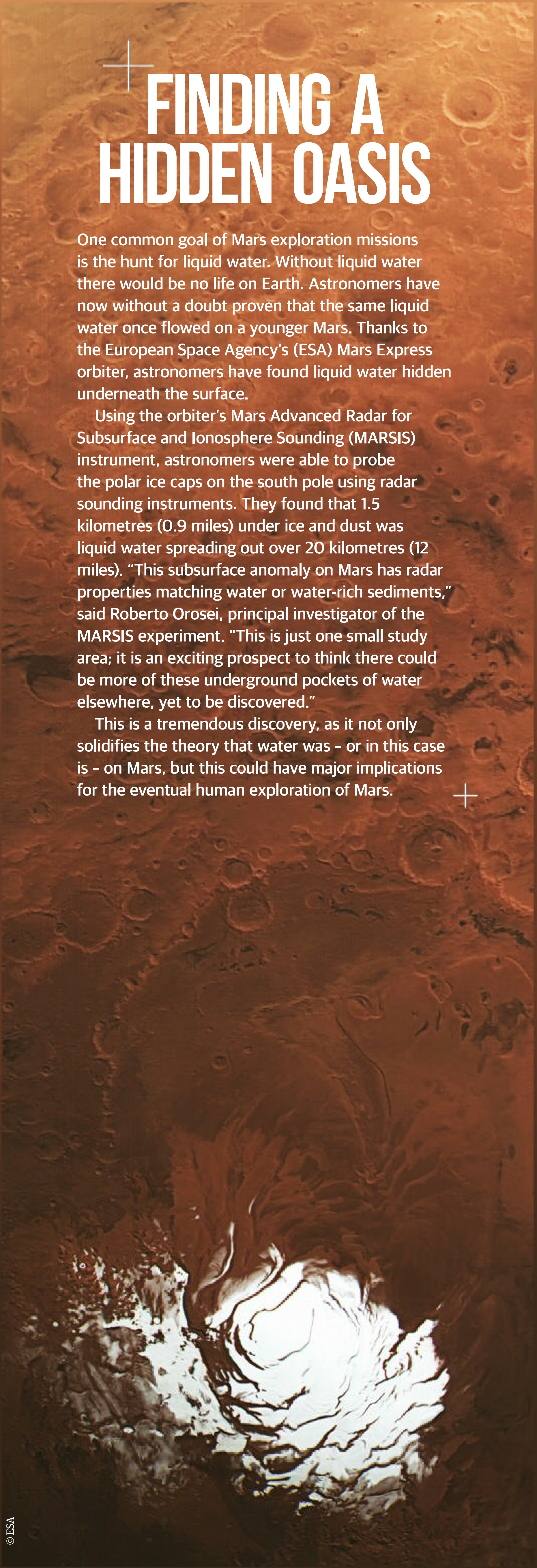
Number of successful and failed missions to Mars by NASA

7 MINUTES

The time taken for a lander to get from the top of Mars' atmosphere to the surface.

2.5X

more radiation experienced at Mars than on the International Space Station.



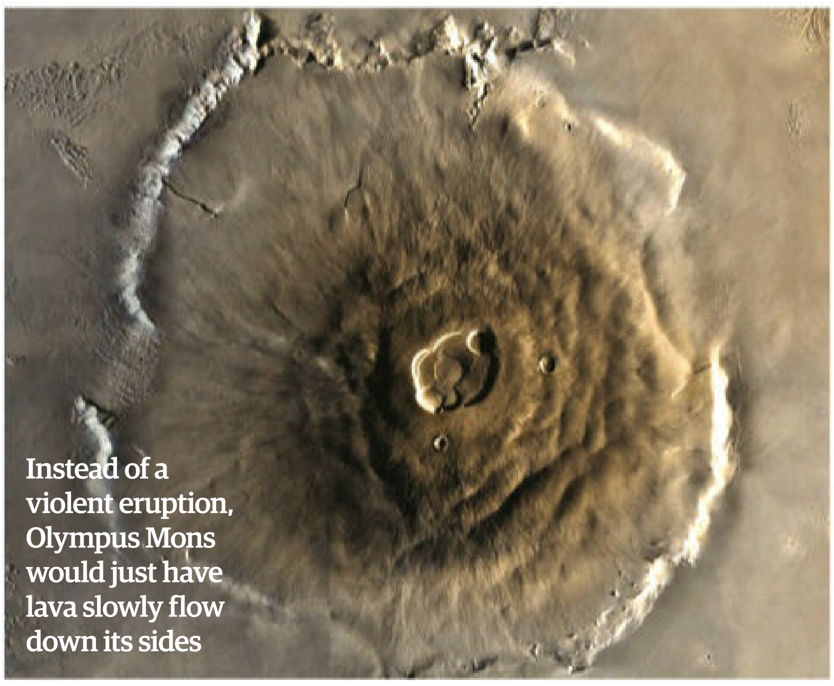
FINDING A HIDDEN OASIS

One common goal of Mars exploration missions is the hunt for liquid water. Without liquid water there would be no life on Earth. Astronomers have now without a doubt proven that the same liquid water once flowed on a younger Mars. Thanks to the European Space Agency's (ESA) Mars Express orbiter, astronomers have found liquid water hidden underneath the surface.

Using the orbiter's Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument, astronomers were able to probe the polar ice caps on the south pole using radar sounding instruments. They found that 1.5 kilometres (0.9 miles) under ice and dust was liquid water spreading out over 20 kilometres (12 miles). "This subsurface anomaly on Mars has radar properties matching water or water-rich sediments," said Roberto Orosei, principal investigator of the MARSIS experiment. "This is just one small study area; it is an exciting prospect to think there could be more of these underground pockets of water elsewhere, yet to be discovered."

This is a tremendous discovery, as it not only solidifies the theory that water was – or in this case is – on Mars, but this could have major implications for the eventual human exploration of Mars.

© ESA



Instead of a violent eruption, Olympus Mons would just have lava slowly flow down its sides

© USGS

PEAKING ABOVE THE DUST CLOUDS

Along with observations of Mars' 'canals' in the 19th century, Schiaparelli also observed more enormous features using his 22-centimetre (8.7-inch) telescope - the Martian mountains. The Tharsis region of Mars was most documented, a huge volcanic plate near the planet's equator and home to the most enormous mountain in the entire Solar System: Olympus Mons.

In fact, even when Mariner 9 made its journey to the Red Planet in 1971, it was able to spot the top of the mountain poking out from a global dust storm.

Olympus Mons is roughly 25 kilometres (16 miles) tall and stretches over 624 kilometres (374 miles) of land - about the size of Arizona in the United States. This giant puts any Earth-based mountains to shame at three-times the height of Mount Everest.

The discovery of Olympus Mons was an exciting one as it posed astronomers with the challenge of explaining its evolution. In doing so astronomers have discovered that although it has been forming for billions of years, some parts of it are still relatively young - only a few millions of years old - and possibly still active.

The early Martian environment was a very different sight to Mars today

© NASA

MARS' FLEETING ATMOSPHERE

The Sun's harmful radiation and solar winds are something that have only become apparent very recently on Earth, especially as we increase our technological presence in space. However, NASA's Mars Atmosphere and Volatile Evolution Mission (MAVEN) orbiter discovered that it was this same intense bombardment that stripped Mars of its atmosphere billions of years ago.

A study in March 2017 using MAVEN data showed that Mars had lost 65 per cent of the argon in its atmosphere to solar wind and radiation. The knock-on effects meant that Mars lost its protective blanket, and without an atmosphere to trap heat or shield from ultraviolet radiation, all the liquid water on Mars was lost. This is why Mars is covered in dried-up riverbeds and minerals that could only exist with the presence of liquid water. This discovery shattered the perception that Mars has always been the dry, red, dusty planet that is seen today.

WHAT'S TO COME

After all the amazing discoveries that human-made space probes have made over the last half a century, what more can be found out? Well, there is certainly more to learn, and a certain NASA mission can offer a fresh insight into Mars.

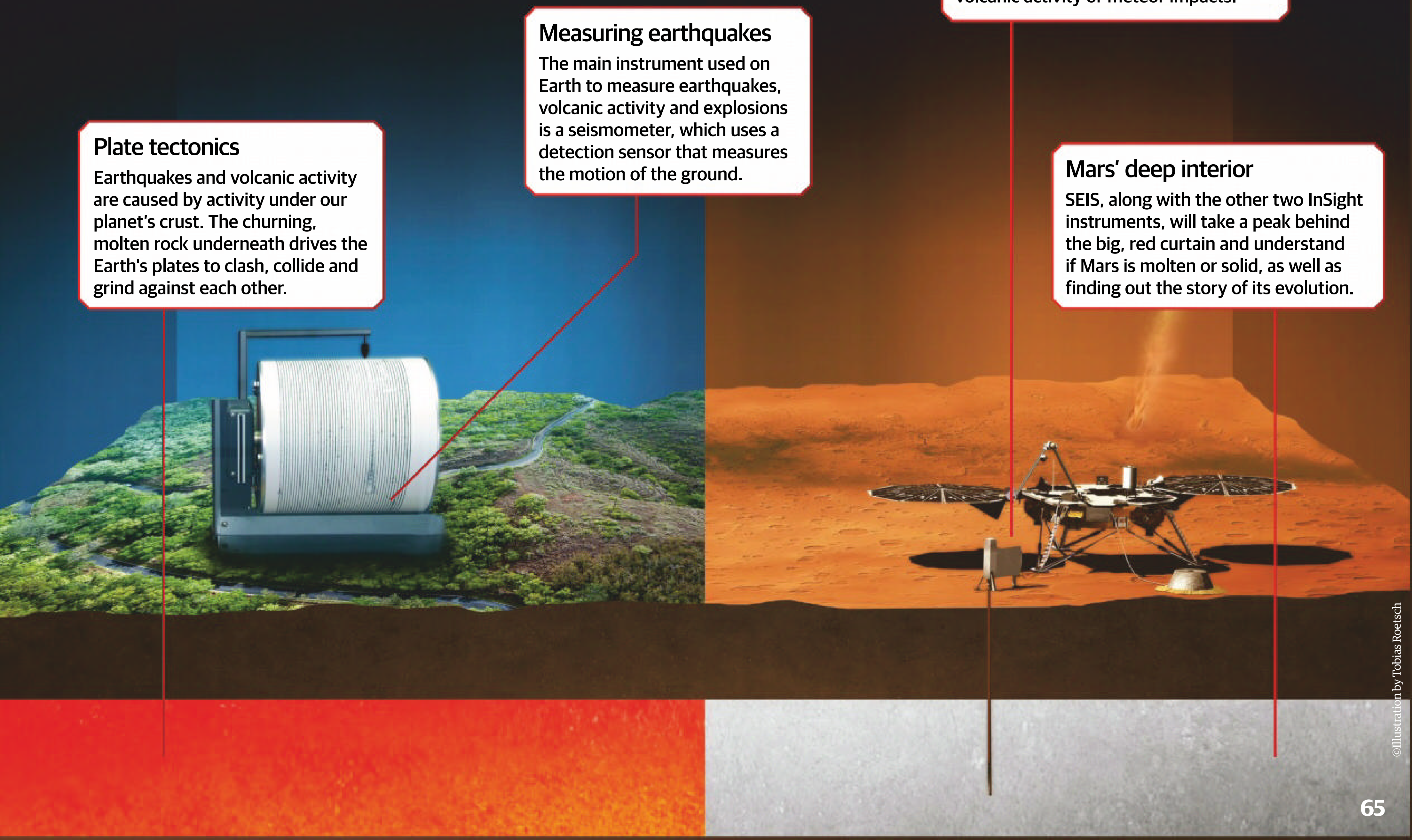
NASA's Interior exploration using Seismic Investigations, Geodesy and Heat Transport, or 'InSight' for short, will probe beneath the surface in order to answer long-standing questions about the planet's deep interior.

It has placed a seismometer, SEIS, on Mars' surface as well as a heat probe, HP^3, and a radio science instrument, RISE, that measures seismic activity, subsurface heat movement and planet-sized wobble that may occur on the Red Planet. This will answer questions not only about Mars' deep interior, but also address questions about the other three rocky Solar System planets – Mercury, Venus and Earth.

> "INSIGHT' WILL PROBE BENEATH THE SURFACE IN ORDER TO ANSWER LONG-STANDING QUESTIONS ABOUT THE PLANET'S DEEP INTERIOR"

EARTHQUAKES VS MARSQUAKES

How will InSight understand the inner workings of our neighbouring planet?



The Seismic Experiment for Interior Structure (SEIS)

NASA's InSight lander depolyed its seismometer on the surface of Mars on 19 December 2018, placed there by its robotic arm. A protective dome was placed over the instrument earlier this year. This will measure any marsquakes, volcanic activity or meteor impacts.

Measuring earthquakes

The main instrument used on Earth to measure earthquakes, volcanic activity and explosions is a seismometer, which uses a detection sensor that measures the motion of the ground.

Plate tectonics

Earthquakes and volcanic activity are caused by activity under our planet's crust. The churning, molten rock underneath drives the Earth's plates to clash, collide and grind against each other.

Mars' deep interior

SEIS, along with the other two InSight instruments, will take a peak behind the big, red curtain and understand if Mars is molten or solid, as well as finding out the story of its evolution.

©Illustration by Tobias Roetsch

ASK Space

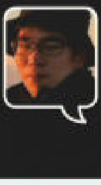
Our experts answer your questions

STARS

If the Sun erupted with a 'superflare', how harmful would it be for life on Earth?

Superflares emit large amounts of dangerous high-energy particles, but life on Earth is protected by a thick atmosphere, and there are almost no effects. However, now is the space age, and there are astronauts in space, and maybe also on the Moon or Mars in the near future. Superflares can cause risks for them since they don't have the shield of the thick atmosphere, so special preparations should be done.

Although superflares do not affect survival for life directly – of course, no life extinction is expected to occur because of superflares – our daily life can be severely damaged by superflares. Now our society and our daily lives are strongly supported by technologies using electricity and satellite communication, for example, GPS. Large plasma ejections, called coronal mass ejections, or CMEs, caused by superflares can generate a large magnetic storm in the Earth's magnetosphere, and this can cause severe damage to electric equipment, for example, transformers, and satellites. One example is the large blackout in Quebec, Canada, in 1989 caused by a relatively large solar flare. At this point, life on Earth – especially human life – could potentially experience a severe solar eruption.



Dr Yuta Notsu is an overseas research fellow at the University of Colorado Boulder and focuses on the study of stellar activity

'Cold quasars' sweep around material at a galactic centre, but still have gas in the outskirts

© Michelle Vigeant

ASTROPHYSICS

What is a 'cold quasar'?

A cold quasar is a very active supermassive black hole whose host galaxy still has a lot of cold gas in it. When supermassive black holes, which lie at the heart of every massive galaxy, are actively accreting new material, they are then known as an active galactic nuclei (AGN). Every galaxy goes through an AGN phase. However, the most massive of galaxies with the most massive of black holes become quasars.

Quasars are the brightest objects in the universe due to how quickly they are accreting material! This material is super-heated as it swirls around the black hole at nearly the speed of light. This turbulence can produce dramatic winds that sweep through the host galaxy, preventing new generations of stars from being formed, and essentially choking the host into becoming a passive, elliptical galaxy.

Usually when we see luminous quasars without any dust in the very centre of the galaxy, the decline in star formation has already begun. Cold quasars were quite a surprise! This rare quasar has swept away dust from the galaxy centre, but the outskirts still have an abundance of cold gas and dust, producing thousands of new stars each year.

Cold quasars are likely at the very beginning of the end. The quasar influence is marching through the galaxy, and soon the host will lose the ability to form new stars and enter the passive phase of its life.

Dr Allison Kirkpatrick is associate professor of physics and astronomy at the University of Kansas

©NASA

There is a colossal size difference between Earth and one of the Sun's superflares

Did you know?

The Carrington Event of 1859 was a huge geomagnetic storm caused by a coronal mass ejection. The storm messed with telecommunications and caused aurorae.

ASTRONOMY

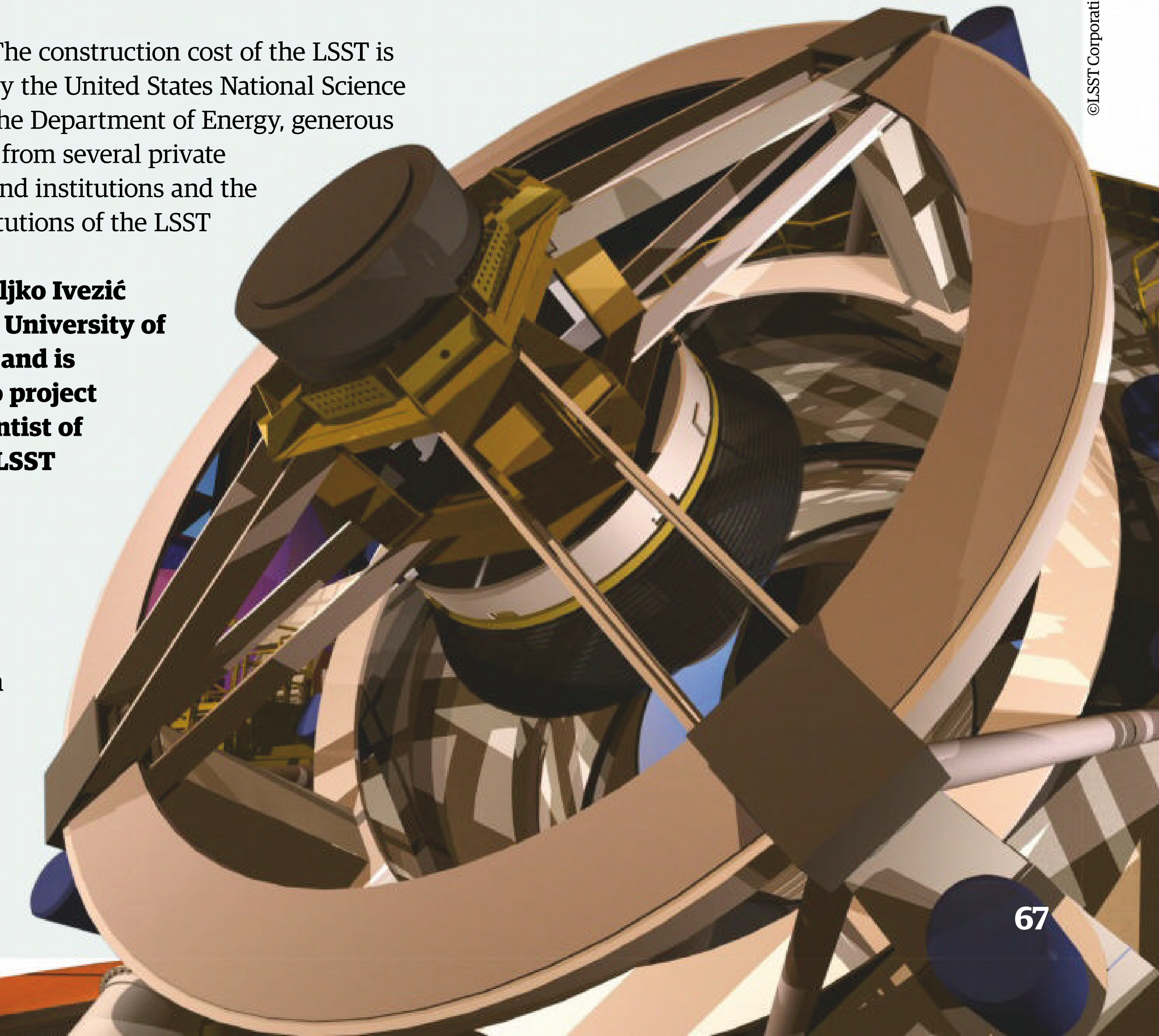
What are the main goals for the Large Synoptic Survey Telescope, and how will they be achieved?

The main goals of the Large Synoptic Survey Telescope (LSST) are to investigate cosmological dark energy and dark matter, take an inventory of the Solar System - including killer asteroids - explore the transient optical sky and map to an exquisite detail our own galaxy, the Milky Way.

The LSST system will have a telescope with an 8.4-metre (28-foot) primary mirror, a very large field of view with a diameter equal to about seven full Moons and a 3,200-megapixel camera, the largest ever used in astronomy. The main ten-year survey will collect about 100 petabytes - one petabyte is equal to a million gigabytes - of imaging data by observing half the sky close to 1,000 times. This data will be processed with a complex set of software pipelines, resulting in databases including about 30 trillion observations of 20 billion galaxies and a similar number of stars.

The project is in the construction phase and will begin regular survey operations from its site in northern Chile by 2022. In addition to science programmes, the operations will include a significant education and public outreach programme. The construction cost of the LSST is being borne by the United States National Science Foundation, the Department of Energy, generous contributions from several private foundations and institutions and the member institutions of the LSST Corporation.

Professor Željko Ivezić works at the University of Washington and is also project scientist of the LSST



©LSST Corporation

The LSST will be staring at the sky for ten years to build a complete survey of the night sky

ASK Space

Our experts answer your questions

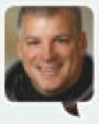
SPACE EXPLORATION

During your time in space, do you feel any significant changes to your body?

It's funny; some of the changes were a little insidious and some were very immediate. Obviously when we get into continuous microgravity, which happens right after main engine cut-off at eight-and-a-half minutes after launch, I think I was laughing more than anything else, as it was so different than standing on the ground.

We also had different physiological changes that happened fairly immediately. You start feeling a little bit of fullness in your head. Some people get nauseated immediately; with me it was kind of a bit more insidious. Most of us had it in just that period, at least the first day or two, and some never actually got over it. This is because your body is just confused. Your vestibular system is accustomed to having fluids settle in the semicircular canals [in your ears], but it just never does, as the fluids just float around in there.

I'm curious as to how long it took me to grow about five centimetres [2 inches] taller. But we did measure ourselves several days into the flight and every one of us had grown a few centimetres. I grew as much as five centimetres. Without gravity continuously pulling through our spines, our bodies get longer. There are other effects also, like vision can shift. Some astronauts experienced vision shifts by up to three dioptres, I understand.



Gregory H. Johnson is a former NASA astronaut who flew as a pilot on two Space Shuttle missions, STS-123 and STS-134

When you take away gravity, your body takes time to adjust to the conditions

© NASA

SOLAR SYSTEM

Why do we need to observe nearby asteroids?

Firstly, by studying them, we are essentially studying fragments that could have ended up as planets, so we can better understand how the planets formed and how they evolved. Near-Earth asteroids are much closer to the Earth, so we can study them in greater detail.

The second reason is practicality. Near-Earth asteroids can potentially collide with the Earth. The Moon, just next to the Earth, is completely pockmarked by impact craters. The smallest asteroids will burn in the Earth's atmosphere, so they are less dangerous. However, because of their inherent motion and because they fall into the Earth's gravity, asteroids hit the Earth at very high speed – at least 40,000 kilometres (25,000 miles) per hour, over ten-times faster than a bullet – so their impacts release a lot of energy. Roughly, the impact of a ten-metre (33-foot) asteroid produces the same quantity of energy as the Hiroshima bomb. Studying nearby asteroids helps to prepare against impacts: if we have enough time – many years – to prepare, the asteroid could be deflected, completely avoiding the collision. If that is not possible, knowing the size, composition and density of the asteroid will help predict how bad the impact will be, and to prepare for it.

Dr Olivier Hainaut is a European Southern Observatory astronomer

Not only is there scientific benefit, there is also the matter of safety

© ESA

Uranus and Neptune are the least observed planets in the whole Solar System

© Tobias Roetsch

Did you know?

Uranus is composed of around 83 per cent hydrogen, 15 per cent helium and two per cent methane. Neptune is around 80 per cent hydrogen and 19 per cent helium.

SOLAR SYSTEM

Why is it essential we find out more about the ice giants, Uranus and Neptune?

Uranus and Neptune have never had a dedicated spacecraft mission, having been visited only once by the brief flyby mission of NASA's Voyager 2 spacecraft three decades ago. These distant ice giants are the least explored type of planet in our Solar System, intermediate between the big hydrogen-rich gas giants - Jupiter and Saturn - and the smaller rocky planets. Yet, Neptune-sized worlds appear to be commonplace in our galaxy, a natural outcome of the chaotic process of planet formation. A mission to these icy worlds is the logical next step in humanity's exploration of our planetary system, to understand how Uranus and Neptune formed, to explore their deep water-rich interiors and exotic hot ices, their stormy atmospheres and their complex magnetic fields, which are totally unlike anything witnessed at Jupiter and Saturn.

> "Neptune-sized worlds appear to be commonplace"

The two worlds are superb examples of how planets with shared origins can go down different evolutionary paths: Neptune as the archetype for ice giants with its seasonal tilt and powerful winds; Uranus as the oddball with its extreme tilted inclination and sluggish atmosphere. And both worlds harbour diverse satellite systems, from Uranus' collection of natural icy satellites with evidence of extreme geological activity to Neptune's captured satellite Triton, a visitor from the more distant Kuiper Belt which may harbour a subsurface ocean and exhibits erupting geysers from its surface. For all these reasons and more, scientists across the globe are urging their space agencies to mount an ambitious robotic mission to explore these worlds in the coming decade.

Dr Leigh Fletcher is a senior research fellow at the University of Leicester who specialises in understanding the giant planets in our Solar System

SPACE EXPLORATION

How does BepiColombo improve on NASA's MESSENGER space probe?

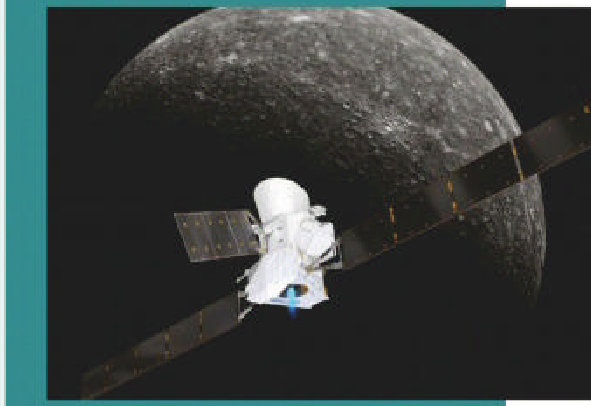
BepiColombo will be perfect to follow up on NASA's MESSENGER.

BepiColombo has several instruments not present on MESSENGER, such as the thermal infrared spectrometer, an accelerometer, a dual-band radio-science instrument and the plasma instruments on the second Japanese spacecraft, Mio, in orbit at the same time.

The ESA's Mercury Planetary Orbiter (MPO) and JAXA's Mercury Magnetospheric Orbiter (Mio) compliment each other. While the MPO is more focused on studying the planet itself and its interior, the MMO is focused on studying the plasma, particle and magnetic environment around the planet. Therefore the BepiColombo mission will provide a rare opportunity to collect multi-point measurements from two craft in a planetary environment.

I strongly believe that the instrumentation of BepiColombo is perfectly suited to obtain our science goals and to deliver new answers to the necessary and new questions raised by MESSENGER.

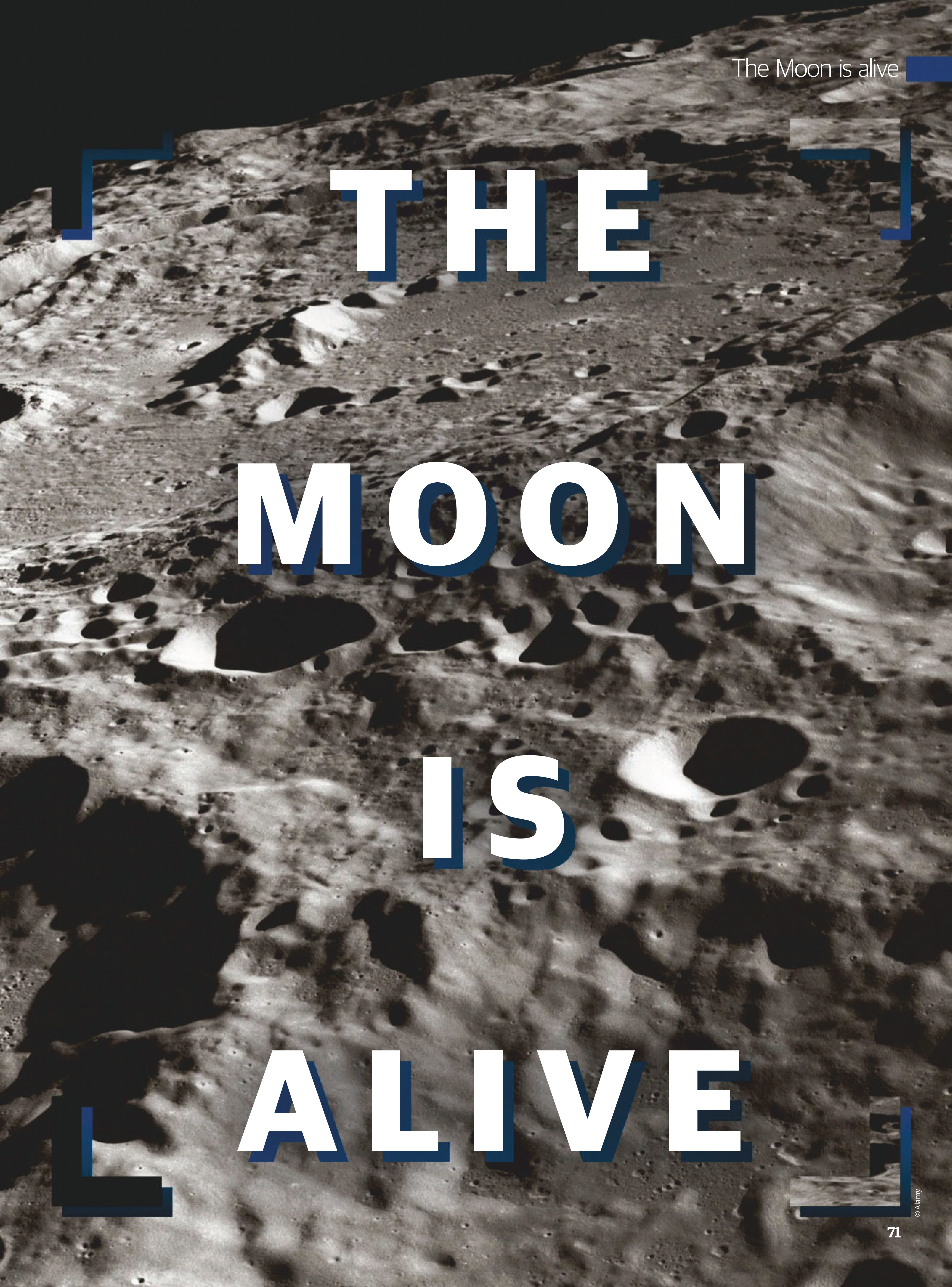
Dr Johannes Benkhoff works at the ESA and is project scientist of the BepiColombo mission



© NASA/JPL

The lunar surface is home to more activity than its barren appearance lets on

Reported by James Romero



THE MOON IS ALIVE

© Alamy

From the 4-billion-year-old, 230-kilometre (143-mile) wide Clavius impact crater to Neil Armstrong's 50-year-old, size-nine-and-a-half 'one small step', the Moon has recorded momentous episodes across much of our Solar System's history.

For scientists its surface provides a 4-billion-year-old astronomical archive of events that shaped both its own peppered surface and our planet too. A passive observer, its record-keeping value lies in the fact that things tend to happen to it, rather than it showing signs of its own activity.

And yet it seems we might have missed something. Something small in size but larger in significance. Located right between the eyes of the 'Man in the Moon', some scientists believe they have found evidence that lunar volcanoes were erupting when dinosaurs roamed the Earth - and perhaps they are still erupting somewhere on the surface right now. If confirmed such activity would tear up current models of the Moon's internal structure and how it evolved, as well as rewriting assumptions about other supposedly 'lifeless' worlds beyond. As missions are proposed to visit this intriguing site, we ask, is the Moon still alive?

A quick glance of its ancient, battered surface offers little hope. The Moon's cratered appearance is in stark contrast to not only the planet it orbits, but also many local, smooth-surfaced planets, dwarf planets and moons. In each case the main concealer of these impact blemishes is volcanism. This recycling of surface crust is familiar to us on Earth, but also accounts for the lack of cratering on Venus, Jupiter's moon Io and even further out to Pluto.

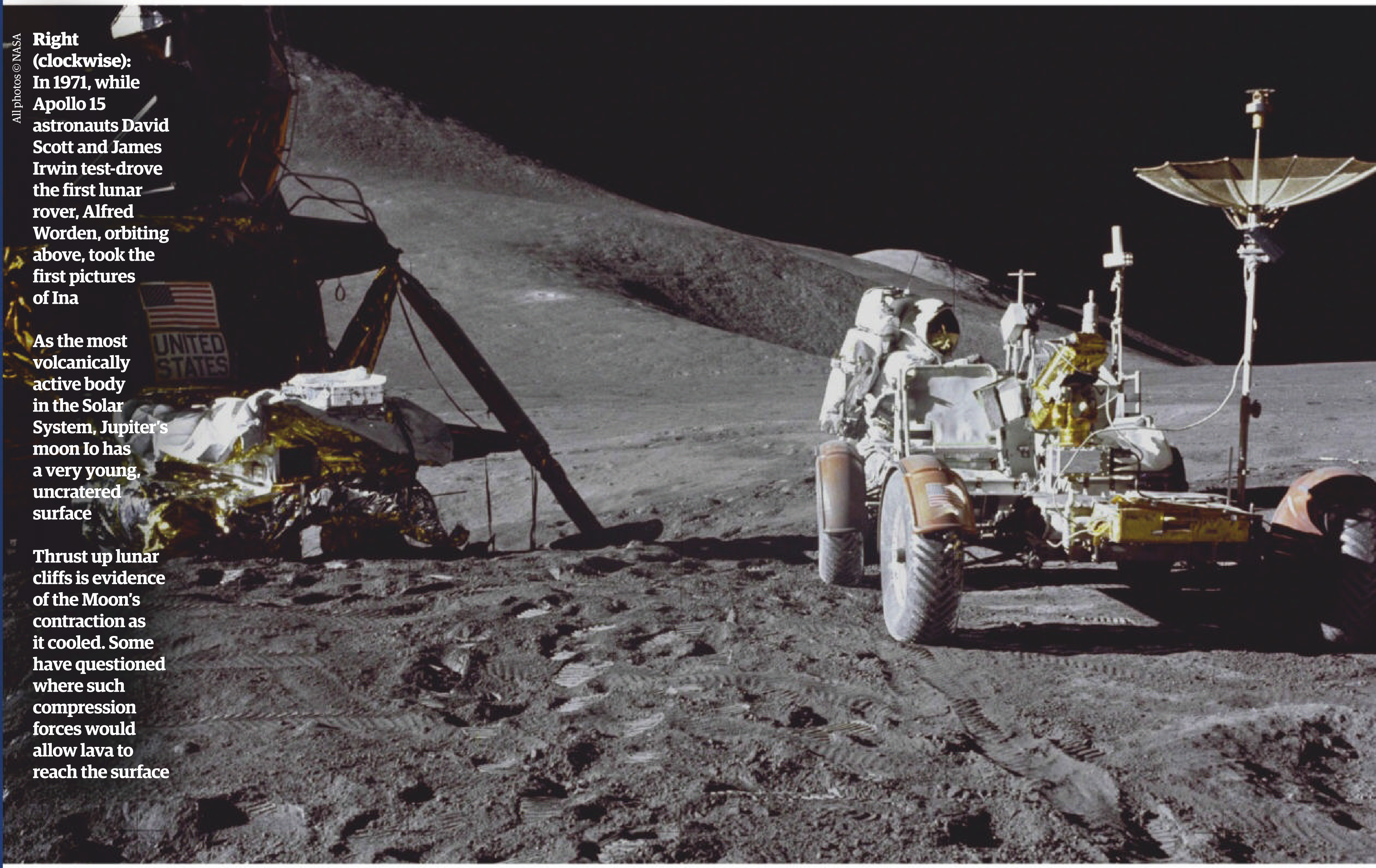
But no such rejuvenation appears to have played out on the lunar surface for a while. While the large, dark mares covered some of the most ancient cratered crust with wide-scale eruptions, billions of years of exposure to Solar System violence has left them sporting plenty of blemishes of their own. The concentration of such cratering dates the mares to between 3 and 4 billion years old, figures backed up by analysis of recovered lunar rock samples. And after that? Well, not much. "We thought that volcanism had ended by 1 billion years ago," says Julie Stopar, a director at the Lunar and Planetary Institute in Houston.

This made sense. The Moon, as a relatively small body, shouldn't have ever had huge amounts of internal heat. And what it had should have been lost quickly due to the large surface area to mass ratio that blights smaller worlds.

This heat might have another effect. Evidence from thrust faults shows the lunar surface shrunk as it cooled, contracting the crust up against itself. This makes it even more difficult to imagine volcanic activity piercing through. But then came a photograph that put that all in doubt.

In 1971, while Apollo 15 astronauts David Scott and James Irwin test-drove the first rover on the lunar surface, Command Module pilot Alfred Worden, orbiting above, took a picture of a strange blotchy feature. Named Ina, it was an exposure of a dynamic landscape - by lunar standards anyway. The Moon's surface is a collection of homogeneously flat vistas covered by broken-up rock and dusty regolith. It's a landscape bombarded into uniform consistency, where any notable topography has been eroded through landslides and impacts over vast eons of time.

> "It is hard to explain how you can have young volcanism based on everything we know about the Moon" **Julie Stopar**


All photos © NASA

Right (clockwise): In 1971, while Apollo 15 astronauts David Scott and James Irwin test-drove the first lunar rover, Alfred Worden, orbiting above, took the first pictures of Ina

As the most volcanically active body in the Solar System, Jupiter's moon Io has a very young, uncratered surface

Thrust up lunar cliffs is evidence of the Moon's contraction as it cooled. Some have questioned where such compression forces would allow lava to reach the surface

Ina is different. It comprises steep, 20-metre (65-foot), smooth-sided mounds surrounded by lower relief, rougher deposits. Like drops of "dirty mercury" on the lunar surface was how astronomer Ewen Whitaker described the mounds, which are typically less than a few hundred meters across. However, with 45-degree slopes, they represent some of the steepest deposits on the Moon. It would be quite a sight. "It will look even more dramatic than even a fresh impact crater," says Stopar. "The rough materials around it will look a bit like a rough sea around the smooth island mounds."

The unusually well-preserved deposits and lack of superposed impact craters led to suggestions Ina was formed by volcanic eruptions during the last 100 million years - possibly gaseous basaltic lava flows surrounded by ashy pyroclastic deposits. "Metre-scale topography cannot survive for long, geologically speaking, due to the constant sandblasting of micro-meteoroid and macro-meteoroid bombardment," says Mark Robinson, a lunar researcher at NASA.

"It certainly looks much younger than anything else on the surface bar the youngest impact craters," observes Stopar. But this was a significant claim at the time, and has been a cause of much debate ever since. "It would totally destroy our current understanding of the thermal history of the Moon," says Lionel Wilson, planetary scientist at Lancaster University and sceptic of the young volcanism hypothesis.

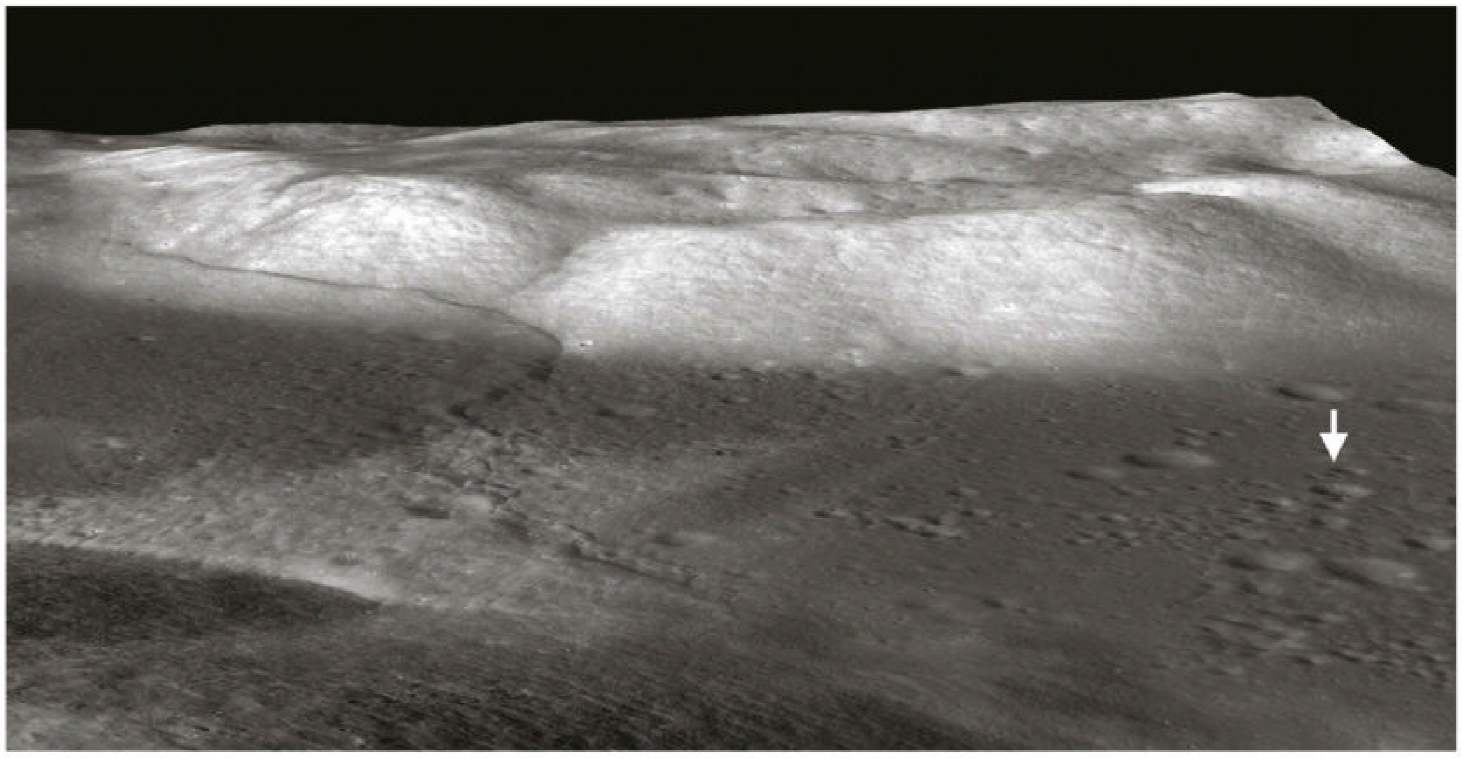
Wilson isn't alone in his hesitance, especially after higher resolution imaging by the Lunar Reconnaissance Orbiter (LRO). In 2012 NASA's Brent Garry argued the lack of crisp fractures, often associated with young volcanic deposits due to the surface cooling quicker than the interior, implies either they eroded over billions of years, or never formed, and therefore Ina was not volcanic. For modellers of the Moon's evolution it is a tempting conclusion. Dismissing the young volcanism hypothesis certainly makes for a better fit with everything we know about our celestial companion.

However, no matter how logical it was to ignore, the suggestion that in Ina we are looking at evidence of a planetary body that is still alive, or at least was very recently, won't go away.

"It is really hard to explain how you can have young volcanism based on everything we know about the Moon. However, others say we can't possibly preserve these features for 3 billion years, so it has to be young," says Stopar. And if Ina was proving hard to explain, the Lunar Reconnaissance Orbiter found 70 similar-looking sites, collectively known as Irregular Mare Patches, or IMPs. And for some IMPs, the evidence for youth might be stronger still.

"There is one IMP located on the ejecta of the Aristarchus crater. This is a young crater that we think is roughly 200 million years old," says Stopar. So we have near-pristine Ina, IMPs seemingly superimposed on crater material only a few hundred million years old, plus a collection of 70 other features for ongoing monitoring. Surely we can allow ourselves to imagine lava spewing out somewhere on the lunar surface today? "It's not much of a stretch," agrees Robinson.

With such a tantalising prospect at stake - not to mention our entire theoretical basis for the structure and evolution of the Moon - a resolution between observation and simulation was required. Theories to account for the ill-fitting Ina and its IMP friends have fallen into two categories: those



How do we know that the Moon is alive?

There are increasing signs of ongoing life

Finding Ina

In 1971 as part of Apollo 15, Alfred Worden took a picture of a strange, blotchy feature. Later named Ina, the exposure represented a uniquely dynamic landscape.

Like liquid drops of mercury

Against a lunar landscape of almost continuous flat vistas covered in a layer of broken-up rock and dusty regolith, Ina's smooth, steep-sided mounds stand out.

Pristine Ina

Ina's unusually well-preserved deposits and lack of superposed impact craters led to suggestions it must be no older than 100 million years old – very recent compared to the lunar surface.

IMP speculation

In 2014 a team from Arizona State University, analysing data from NASA's LRO, found 70 similar-looking sites to Ina, which are collectively known as Irregular Mare Patches.

Patchy Aristarchus

One IMP is located on top of the ejecta of the Aristarchus crater. This fresh crater is itself only 200 million years old, providing further evidence this new class of lunar features are young.

IMP concentration

Grouping of IMP sites in one region might provide additional support for young volcanism by reducing the amount of internal heat the Moon needs to have retained to power them.

Water on the Moon

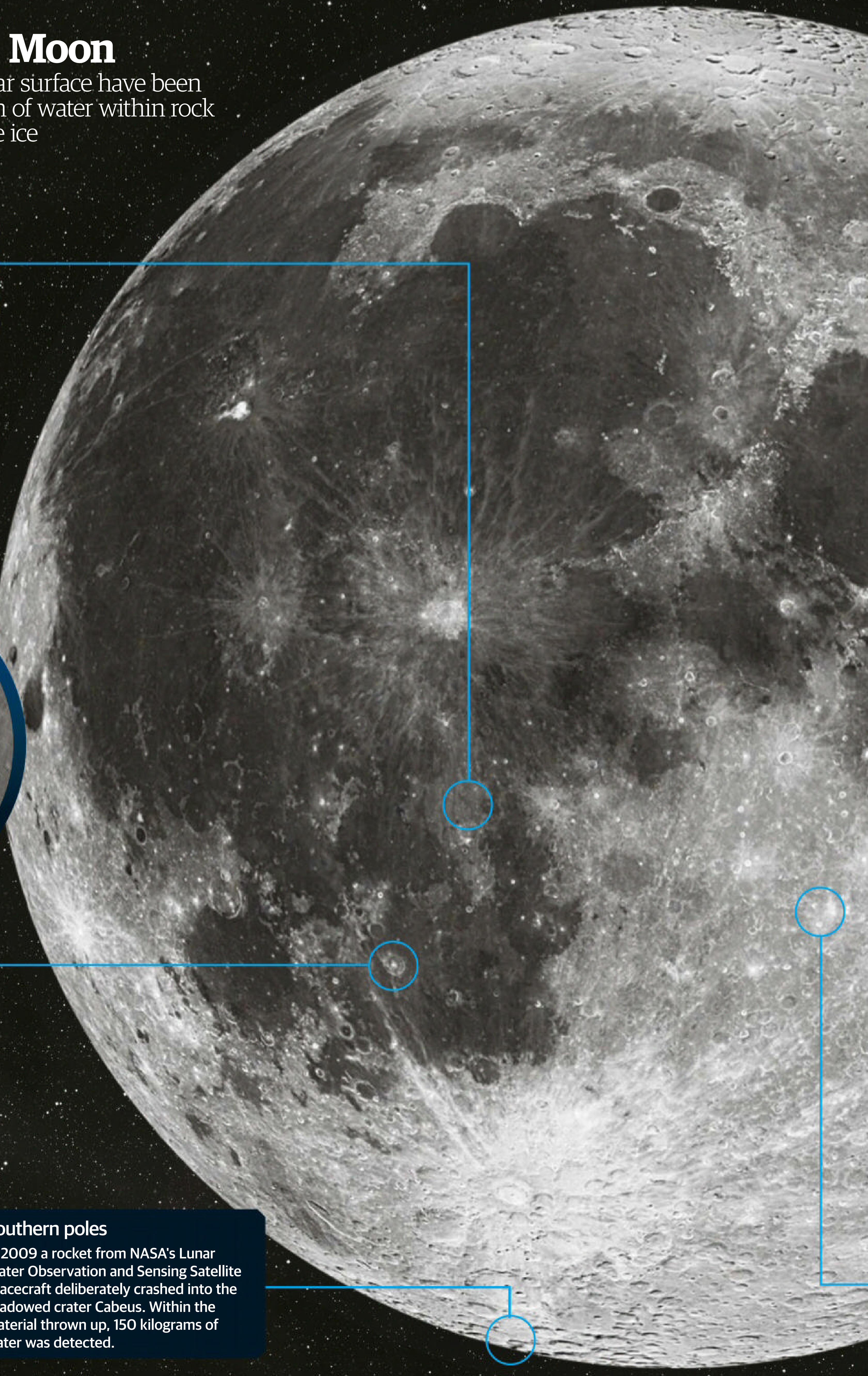
Ideas of a bone-dry lunar surface have been overturned by detection of water within rock minerals, and as surface ice

Fra Mauro Highlands

The samples collected from the Apollo 14 landing site were in 2008 found to include minerals containing water in the form of hydroxyl, a chemical that includes hydrogen and oxygen.

Bullialdus crater

In 2013 a team at John Hopkins University analysing spectroscopic data from the Moon Mineralogy Mapper detected magmatic water in the central peak of this impact crater.



Southern poles

In 2009 a rocket from NASA's Lunar Crater Observation and Sensing Satellite spacecraft deliberately crashed into the shadowed crater Cabeus. Within the material thrown up, 150 kilograms of water was detected.

Spacecraft

Chandrayaan-1

The first Indian lunar probe spent almost a year in orbit. It contained the Moon Mineralogy Mapper imaging spectrometer instrument that provided the first high-resolution spatial and spectral map of the entire lunar surface.

Lunar Crater Observation and Sensing Satellite

Launched after the first detection of water by Chandrayaan-1, LCROSS was envisioned as a low-cost means of determining the nature of hydrogen detected at the polar regions of the Moon.

NASA's Clementine

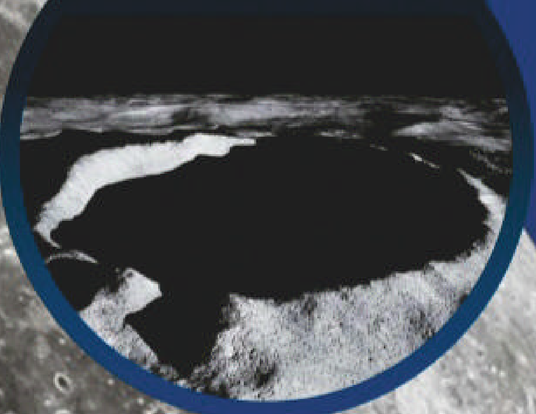
Clementine found early evidence of water ice after scanning the surface with radar in 1996. However, follow-up observations with radio telescopes suggested the spots surveyed had too much Sun exposure for ice to survive.

Lunar Prospector

The 19-month mission was designed for a low-polar orbit investigation of the Moon. This included mapping the surface composition and locating lunar resources, measuring magnetic and gravity fields and studying outgassing events.

Shackleton Crater

Perpetually in shadow, the crater provides a cold trap to freeze water from comet impacts. The Lunar Prospector spacecraft revealed higher than normal amounts of hydrogen, indicative of water ice.



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Taurus-Littrow valley

As well as water within minerals from the lunar interior, the Apollo samples, like those from Apollo 17, reveal water inside crustal rocks, thought to be evidence of younger volcanic intrusions.

Rozhdestvenskiy crater

In 2018 a Hawaiian team found evidence of surface-exposed water ice within reflectance spectra of indirect lighting from the crater's permanently shadowed regions.

Descartes Highlands

Modern analysis of various lunar samples, including those from this Apollo 16 site, have revealed water inside apatite minerals of the lava plains that arise deep within the Moon.

> "A lot of the patches are found in areas where we think volcanism could have lasted the longest" **Julie Stopar**

maintaining Ina is old have given it a facelift. In 2006 Peter H. Schultz at Brown University proposed a spring clean via later subsurface outgassing that removed the overlying regolith, while Le Qiao, visiting Brown, suggested a recent collapse into a subsurface void.

Wilson was involved in a 2017 paper advocating the replacement of standard mare basalt lava with a more exotic variety that degrades differently, creating the illusion of youth. Their lava of choice is a gas-rich magmatic foam, like an extreme pumice. While critics have questioned how such a fragile deposit could survive billions of years of micrometeorite impacts, Wilson believes his solution could link IMPs to the origin of the mare basalts themselves. "Maybe IMPs are places where there were vents? During the very last stage of the mare eruptions, it [the lava] is not flooding out any more. The bulk of the gas comes out in intermittent explosions and gas-filled lavas."

On the other side are those trying to keep the Moon volcanically active long enough to account for eruptions in the last 100 million years. One way might be to ignore the vast majority of it. Most IMPs are located in the same area, along with elevated concentrations of thorium, a radioactive source of internal heating in subsurface rocks. "A lot of the patches are found in areas where we think volcanism could have lasted the longest. Perhaps as recently as 50 to 60 million years ago," suggests Stopar. And if the last vestiges of lunar internal heat had stuck around beneath certain parts of the surface, perhaps occasional upwellings might not

All photos © NASA

Volcanoes on the Moon

The Moon has been volcanically active for most of its history

Pre-Nectarian period

Lunar crust formed via mineral crystallisation of a global magma ocean, forming the lunar highlands. With liquid surface volcanism not possible, hot vapour release did create an atmosphere, however.

Early Imbrian epoch

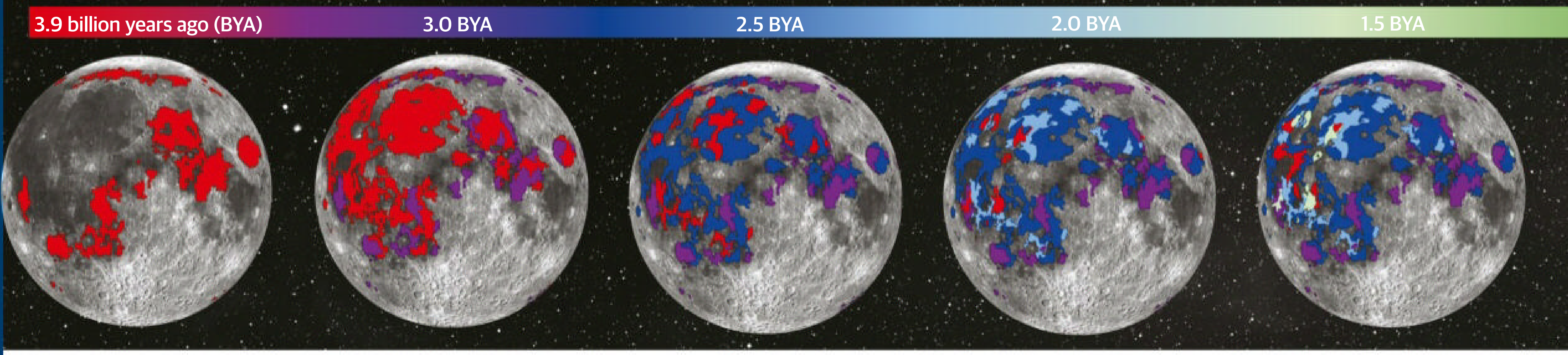
The mantle lying below the lunar basins melted due to frequent giant meteorite impacts that came with the late heavy bombardment and thinned the overlying crust.

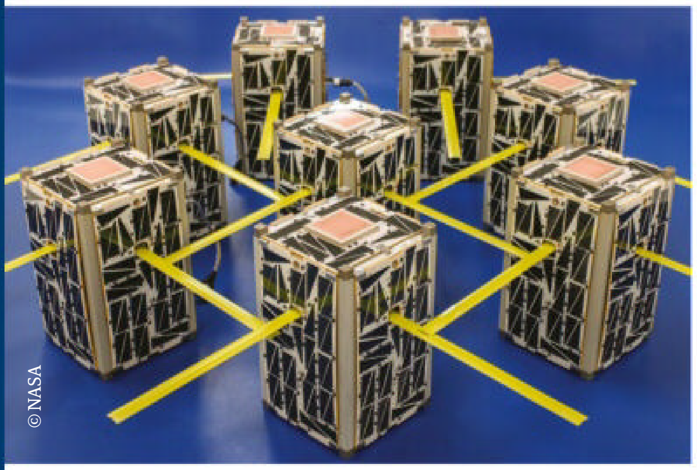
Late Imbrian epoch

The thinned crust led to peak rates of effusive wide-ranging basalt eruptions, creating the famous mare, the dark, smooth lowlands of the Moon. There is also evidence of occasional pyroclastic eruptions.

Eratosthenian period

The massive basaltic volcanism of the Imbrian period tapered off and ceased. During this era late-stage volcanism filled low-lying regions in and around Mare Imbrium and Oceanus Procellarum.




© NASA

have had such a tough job reaching the surface. This was one conclusion of earlier work, again involving Stopar, which challenged the locked-up surface hypothesis. "There are lots of young tectonic features on the Moon that suggest the crust is still moving around," she explains.

While Robinson sees Ina and the other IMPs as compelling evidence for lunar volcanism in the last few 100 million years, Stopar sees problems with both hypotheses, and Wilson is maintaining his scepticism. "The discussion can get quite heated," he says.

Above: Planetary scientist Julie Stopar has proposed a 'fast and cheap' SmallSat lander mission to visit Ina and look for signs of recent volcanism

The constant recycling of rock through plate tectonics and volcanism across Earth's history makes it a poor record of planetary and Solar System history

© Getty

One way out of the impasse would be to visit an IMP, with Ina preferred due to its size and history of being studied. While the Lunar Reconnaissance Orbiter is providing the best-ever images of the surface, the evidence of collapse features or recent volcanism on the sub-metre scale is unlikely to be resolved. "We actually have to be there. It requires us looking into the soil on the landform. I don't think we can get that from orbit," argues Stopar.

But who is 'we'? In the same year US Vice President Mike Pence called on NASA to return American astronauts to the Moon by 2024, is Stopar suggesting setting up camp around the base of Ina and mounting its smooth slopes? Not exactly.

Putting a geologist on the Moon has benefits. There are many interesting sites where complex scientific questions could be chipped away. These include the south pole, where elevated concentrations of rare lunar water could explain our own blue planet. This is one reason the US has targeted it for a lunar base.

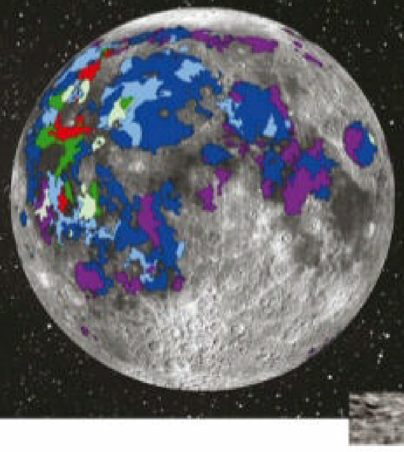
The Ina mystery is different. It represents a relatively straightforward puzzle where we think we know what we are looking for. The key indicators include the small fractures that Garry couldn't see from orbit, lava flow textures and collapse pits, as well as the general size, shape, porosity and mineralogical content of surface grains, which should all be indicative if derived from broken-up foamy lavas. In fact, so well defined is the question that Stopar and colleagues have offered to answer it for just $100 million, a knock-down price in planetary exploration.

For that money you get the Irregular Mare Patch Exploration Lander, or IMPEL, a SmallSat mission proposed this April in the journal *Planetary and Space Science*. The lander would carry a mast camera for high-resolution colour imaging of the landing site, and a microscopic imager for close-up analysis of the surface regolith and any signs of

Copernican period

It is generally thought lunar volcanism had ceased by the Copernican period. However, evidence from Ina and 70 other similar-looking mare patches suggest small-scale volcanism may have continued.

1.0 BYA



Above: NASA's Lunar Reconnaissance Orbiter has returned images of 70 similar-looking sites to Ina, collectively known as Irregular Mare Patches

© NASA

fracturing. "It's a great idea," says Wilson. "It's a fast and cheap mission. And that is not a criticism."

However, while he sees the potential for great science, he doubts IMPEL alone can date Ina. "Detailed morphological studies by a lander would be enormously useful in establishing exactly what happened, but only radiometric dating will convince me of when." However, he still sees value in SmallSats to answer this question. In fact, Wilson suggests sending more. "Why not send five of these things to five candidate IMPs to establish the most interesting one, then send the larger mission to collect samples."

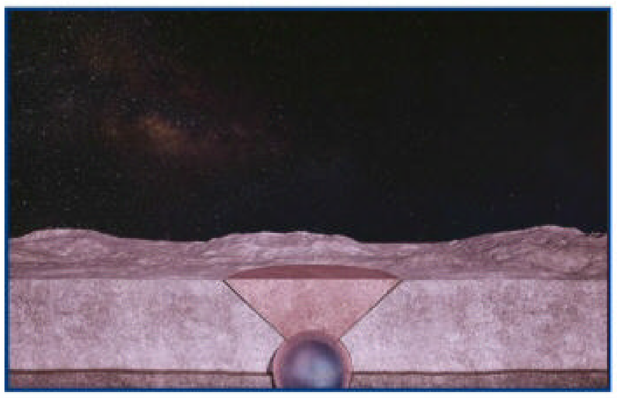
In the meantime the rest of the community is left with orbital images. Here there have been no signs of any structural changes that could indicate present-day activity. "It is still a leap to say it [the Moon] is still active today," states Stopar. "However this could be based on the limited timetable we have been observing."

"If any form of observation were to capture unambiguous images of any actual eruption, then of course I would accept that there is something fundamentally wrong with our current understanding of the Moon's interior - and relish trying to understand what we have been doing wrong all these years," says Wilson.

Stopar believes the implications of such a discovery might go well beyond the lunar interior. If the Moon could support recent volcanism, then we would need to re-examine assumptions about other small moons and dwarf planets. This includes whether the same mechanism for preserving residual heat could be keeping sub-surface water liquid elsewhere, maintaining more of the oceans known to exist within Jupiter's Europa and Saturn's Enceladus. "We need to go there to Ina because it is a place where we can answer a really important question with big implications, just based on this one small area," Stopar concludes.

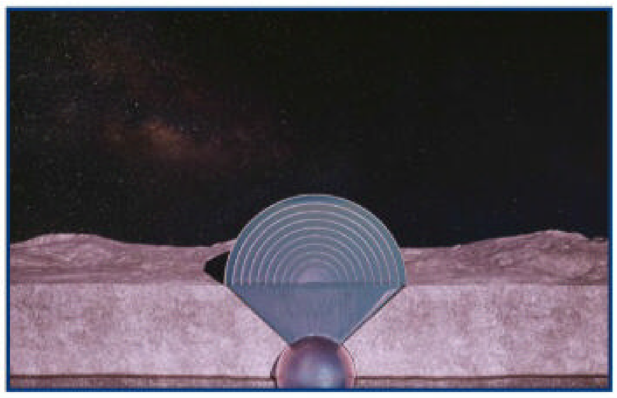
The Moon's explosive outgassing

Outbursts could explain the appearance of the lunar surface



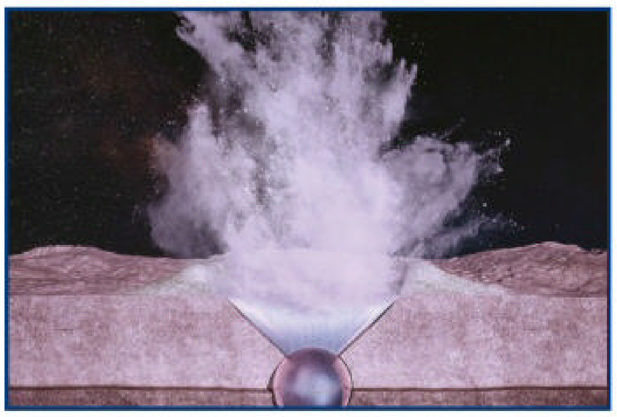
1. Building up of gas

Gas builds up between the lunar megaregolith and the upper layer of regolith (which has a low diffusivity). The pressure is built up by the gas, lifting a cone of material to the surface.



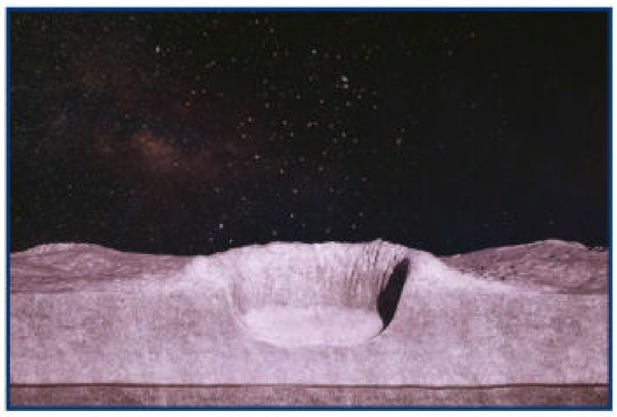
2. Mixture of gas and material

The concoction of regolith and gas now creates a substantial volume on the surface. It's filled with shells of regolith particles. The cloud of matter and gas expands.



3. Moon matter escapes to crater

The cloud continues to expand until it reaches a point where it's not very thick when viewed from above. Regolith that has fallen from the gas cloud piles up around the crater.



4. All gas escapes

All of the gas starts to leak out and any lunar material that was trapped within the cloud has managed to escape. It is deposited onto the ground around and inside the 'impact'.

Illustrations © Nicholas Forder

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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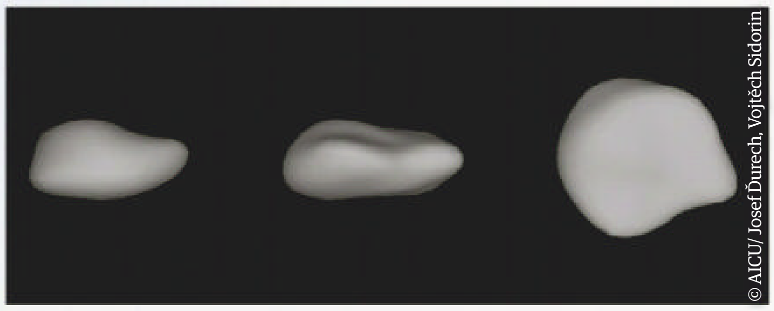
What's in the sky?

© Adam Block/Mount Lemmon SkyCenter/University of Arizona

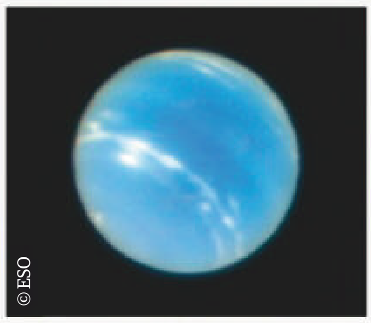
15 AUG
Venus is at greatest brightness, shining at magnitude -3.9 at sunset

22 AUG
Comet 168P/Hergenrother is predicted to reach its brightest at magnitude 11.5 in Perseus

6 SEP
Asteroid 135 Hertha is well placed for observation in Aquarius


© AICU/ Josef Durech, Vojtěch Sidorin

9 SEP
The Piscids reach their peak of around ten meteors per hour


© ESO

10 SEP
Neptune is well placed for observation in Aquarius

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

15 AUG

Globular cluster Messier 2 is well placed for observation in Aquarius

© ESA/Hubble & NASA

17 AUG

Asteroid 39 Laetitia is well placed for observation in Capricornus

21 AUG

The alpha-Cygnids will reach their peak of five meteors per hour

6 SEP

Conjunction between the Moon and Jupiter in Ophiuchus

6 SEP

The Moon and Jupiter make a close approach, passing within 2°15' of each other in Ophiuchus

8 SEP

Conjunction between the Moon and Saturn in Sagittarius

8 SEP

The Moon and Saturn make a close approach, passing within 0°02' of each other in Sagittarius

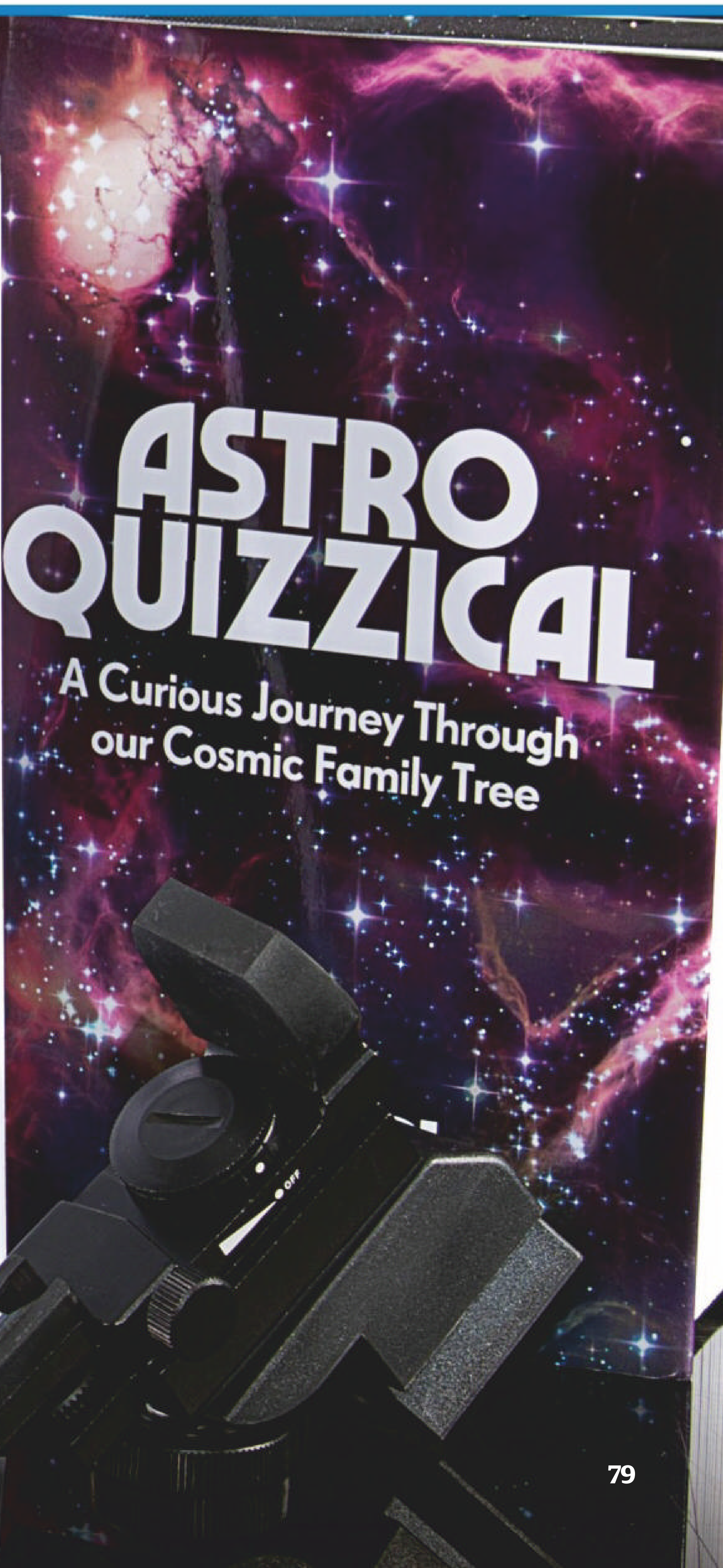
9 SEP

The Moon and Pluto make a close approach, passing within 0°03' of each other in Sagittarius

10 SEP

Comet 260P/ McNaught makes its closest approach to the Sun in the dawn sky

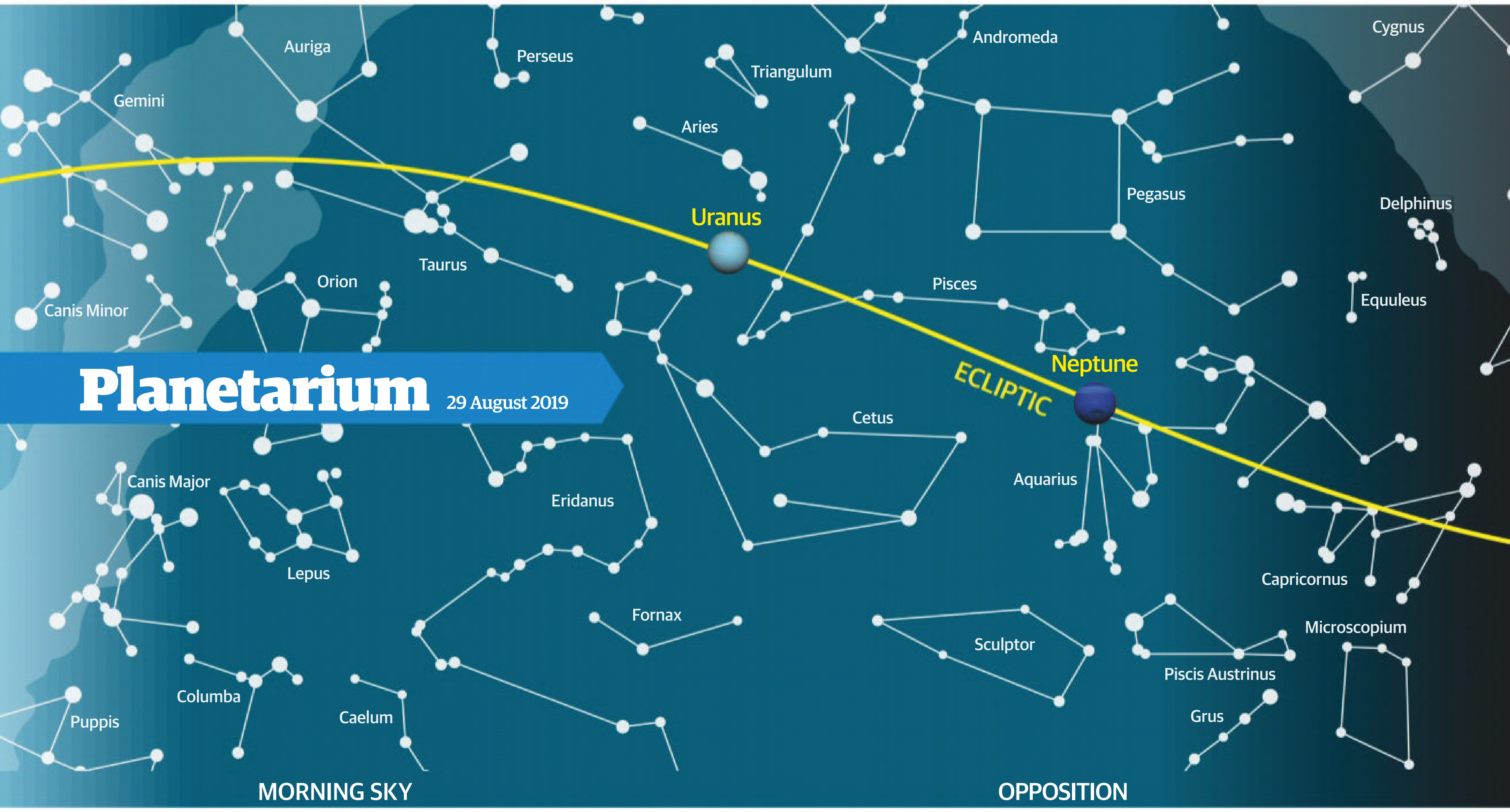
Naked eye
Binoculars
Small telescope
Medium telescope
Large telescope



STARGAZER

Planetarium

29 August 2019



Moon calendar

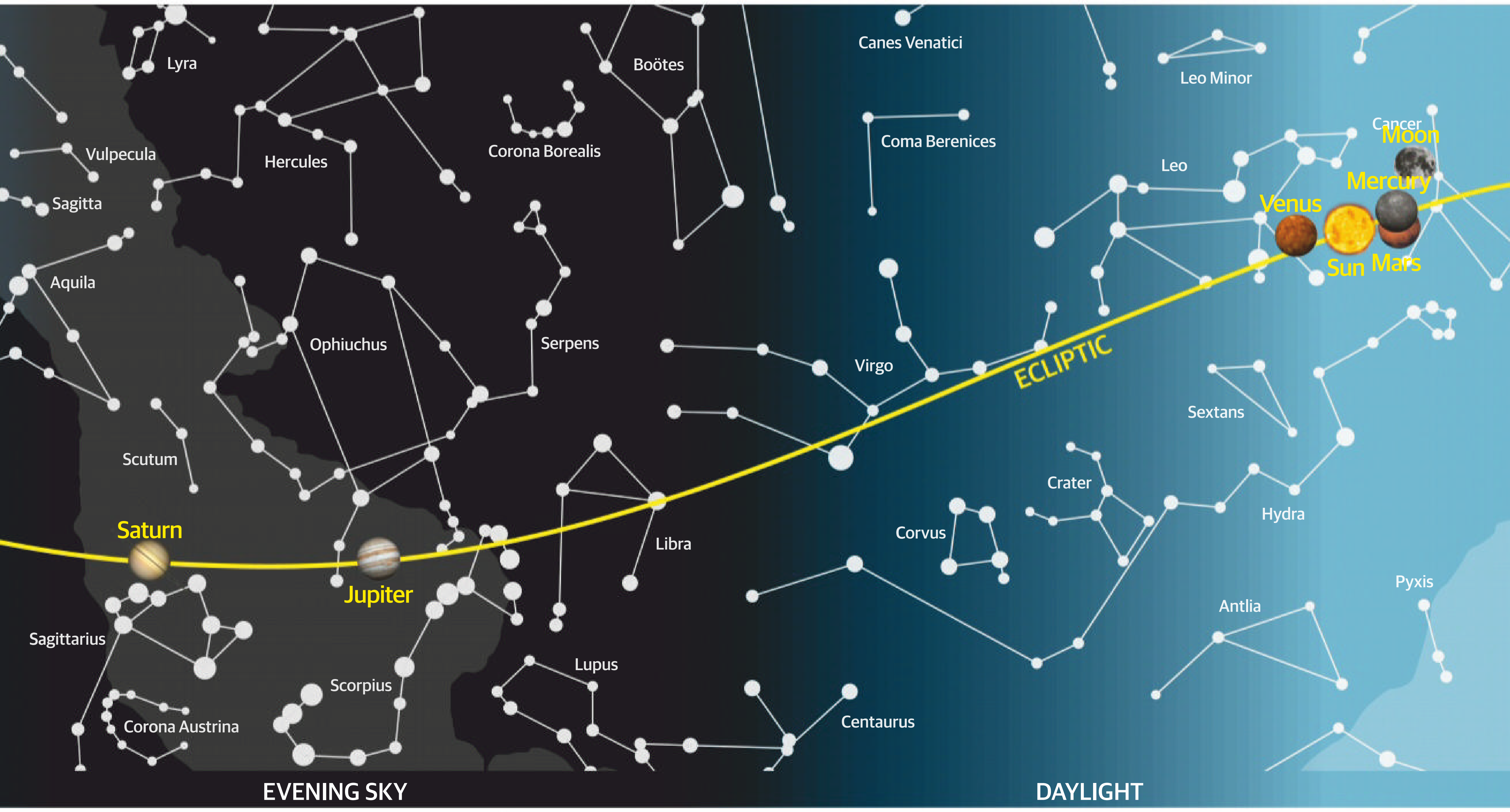
* The Moon does not pass the meridian on 12 September

			15 **AUG** FM 99.7% ◒05:17 ◓20:47	**16** **AUG** 99.7% ◒06:23 ◓21:09	**17** **AUG** 97.8% ◒07:28 ◓21:29	**18** **AUG** 94.1% ◒08:34 ◓21:47
19 **AUG** 88.7% ◒09:40 ◓22:05	**20** **AUG** 81.8% ◒10:45 ◓22:23	**21** **AUG** 73.6% ◒11:52 ◓22:42	**22** **AUG** 64.3% ◒13:01 ◓23:04	**23** **AUG** LQ 54.1% ◒14:11 ◓23:31	**24** **AUG** 43.5% ◒15:22 ◒--:--	**25** **AUG** 32.7% ◓00:05 ◒16:31
26 **AUG** 22.5% ◓00:49 ◒17:34	**27** **AUG** 13.3% ◓01:46 ◒18:30	**28** **AUG** 6.1% ◓02:56 ◒19:15	**29** **AUG** 1.5% ◓04:16 ◒19:51	**30** **AUG** NM 0.1% ◓05:42 ◒20:21	**31** **AUG** 2.1% ◓07:09 ◒20:47	**1** **SEP** 7.1% ◓08:35 ◒21:10
2 **SEP** 14.8% ◓10:00 ◒21:33	**3** **SEP** 24.3% ◓11:22 ◒21:57	**4** **SEP** FQ 34.9% ◓12:41 ◒22:23	**5** **SEP** 45.9% ◓13:56 ◒22:54	**6** **SEP** 56.7% ◓15:06 ◒23:31	**7** **SEP** 66.9% ◓16:09 ◒--:--	**8** **SEP** 76.1% ◒00:16 ◓17:03
9 **SEP** 84.1% ◒01:07 ◓17:47	**10** **SEP** 90.6% ◒02:06 ◓18:22	**11** **SEP** 95.4% ◒03:09 ◓18:51	**12** **SEP** FM --:--*% ◒04:14 ◓21:29			

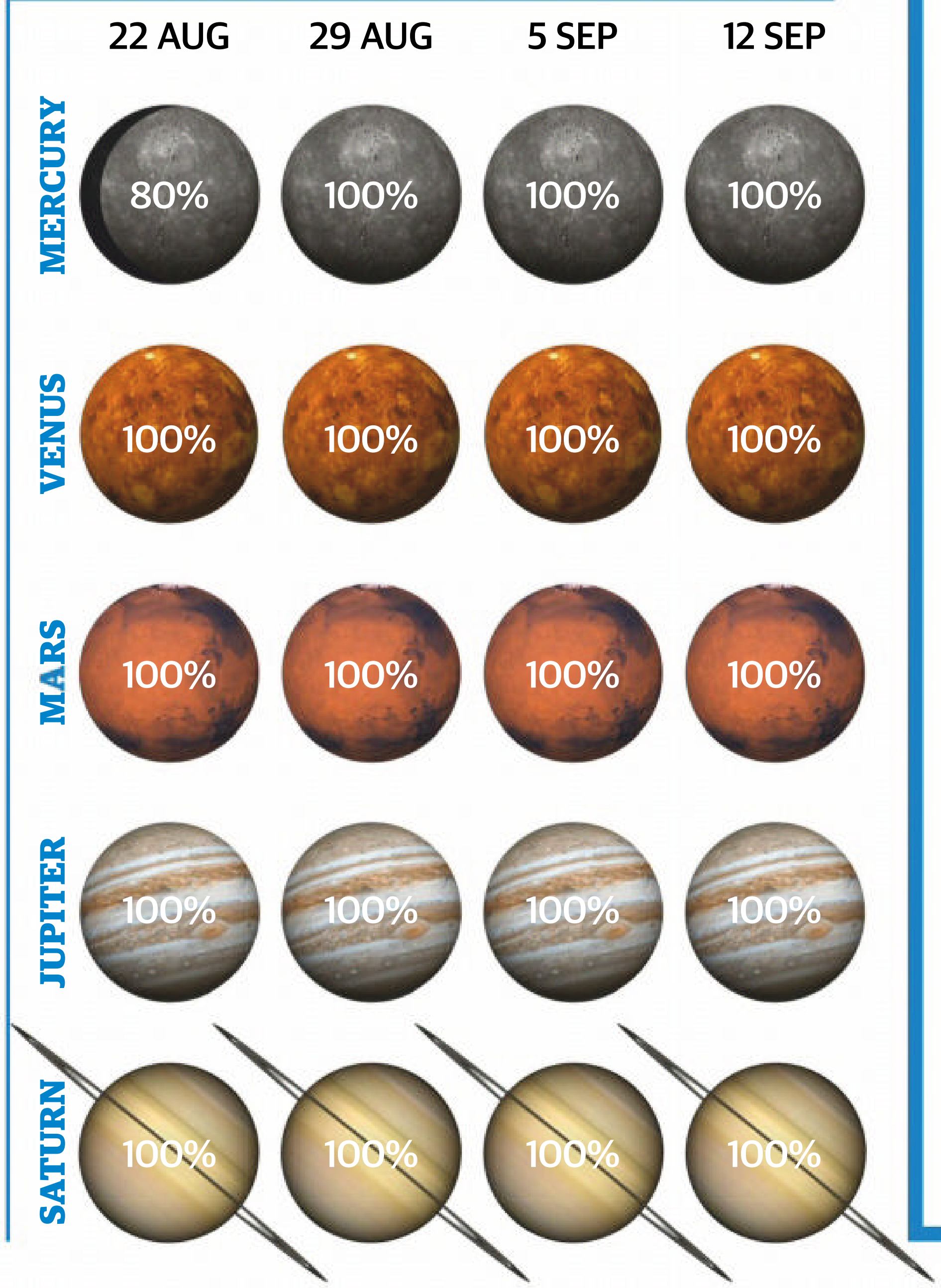
% Illumination
◓ Moonrise time
◒ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



	22 AUG	29 AUG	5 SEP	12 SEP
MERCURY	80%	100%	100%	100%
VENUS	100%	100%	100%	100%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

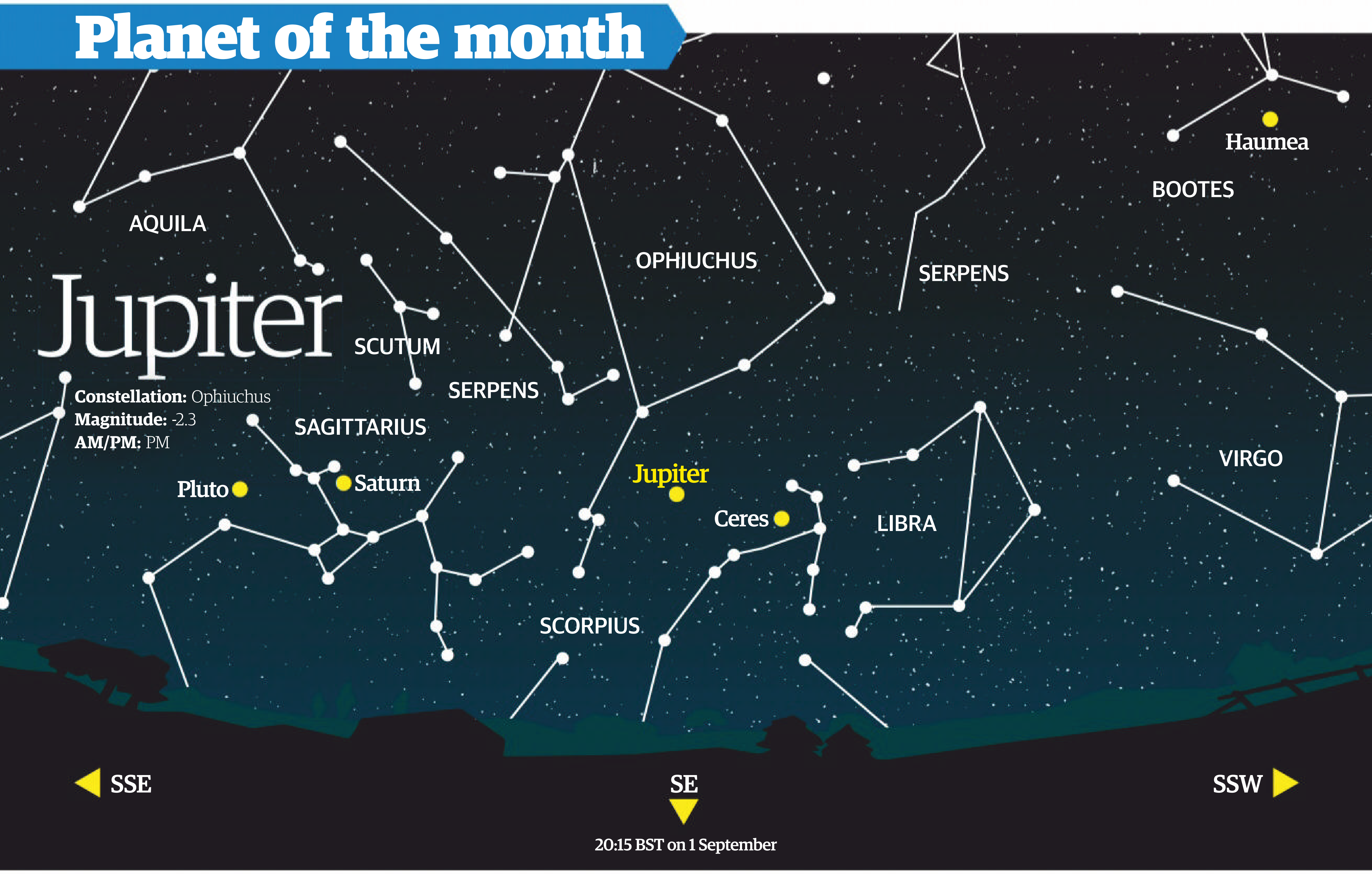
All rise and set times are given in BST

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	15 Aug	08h 24m 17s	+19°10'03"	Cancer	0.6	04:12	19:48
	22 Aug	09h 13m 09s	+17°18'24"	Cancer	0.8	04:45	19:57
	29 Aug	10h 07m 23s	+13°24'44"	Leo	-1.6	05:34	20:01
	05 Sep	10h 59m 06s	+08°18'07"	Leo	-1.8	06:26	19:58
	12 Sep	11h 46m 04s	+02°47'41"	Leo	-1.1	07:13	19:49
VENUS	15 Aug	09h 38m 36s	+15°26'10"	Leo	-3.9	05:49	20:39
	22 Aug	10h 12m 17s	+12°34'39"	Leo	-3.9	06:11	20:29
	29 Aug	10h 45m 13s	+09°26'21"	Leo	-3.9	06:33	20:17
	05 Sep	11h 17m 33s	+06°05'27"	Leo	-3.9	06:56	20:05
	12 Sep	11h 49m 27s	+02°36'07"	Virgo	-3.9	07:18	19:51
MARS	15 Aug	10h 01m 06s	+13°19'58"	Leo	1.8	06:23	20:50
	22 Aug	10h 18m 08s	+11°45'02"	Leo	1.8	06:21	20:30
	29 Aug	10h 35m 00s	+10°06'29"	Leo	1.7	06:20	20:11
	05 Sep	10h 51m 43s	+08°24'52"	Leo	1.7	06:18	19:51
	12 Sep	11h 08m 19s	+06°40'42"	Leo	1.8	06:16	19:31
JUPITER	15 Aug	16h 51m 52s	-22°07'01"	Ophiuchus	-2.4	16:24	20:26
	22 Aug	16h 52m 29s	-22°09'21"	Ophiuchus	-2.3	15:58	00:05
	29 Aug	16h 53m 45s	-22°12'38"	Ophiuchus	-2.3	15:32	23:34
	05 Sep	16h 55m 38s	-22°16'48"	Ophiuchus	-2.2	15:07	23:08
	12 Sep	16h 58m 07s	-22°21'44"	Ophiuchus	-2.2	14:42	22:42
SATURN	15 Aug	16h 51m 52s	-22°07'01"	Ophiuchus	-2.4	16:24	00:32
	22 Aug	16h 52m 29s	-22°09'21"	Ophiuchus	-2.3	15:58	00:05
	29 Aug	16h 53m 45s	-22°12'38"	Ophiuchus	-2.3	15:32	23:34
	05 Sep	16h 55m 38s	-22°16'48"	Ophiuchus	-2.2	15:07	23:08
	12 Sep	16h 58m 07s	-22°21'44"	Ophiuchus	-2.2	14:42	22:42

This month's planets

While Mercury, Venus and Mars have all let us down this month, Jupiter is putting on a show, craving our attention

Planet of the month



Jupiter

Constellation: Ophiuchus
Magnitude: -2.3
AM/PM: PM

20:15 BST on 1 September

Jupiter is by far the largest planet in the Solar System. A bloated gas giant world so huge it could contain a thousand Earths with room to spare, this behemoth of a world is so far from the Sun it takes a dozen years to orbit it. This actually works out quite well for us because that means it moves very slowly across our night sky, lingering in one of the zodiacal constellations for a year at a time. At the moment it is in Ophiuchus, the 'forgotten' zodiacal constellation, forgotten because you'll never see it featured in any astrologer's horoscope even though the Sun and planets move through it just as they do through more famous constellations such as neighbouring Sagittarius and Scorpius.

All through our observing period Jupiter is a striking 'evening star', visible above the southern horizon as soon as the sky begins to darken after sunset. Although it isn't very high - which means that if you have hills, buildings or even just tall trees on your southern horizon they might hide it from your view - its magnitude of -2.3 means it is an easy naked-eye object, visible without any help from binoculars or a telescope, and you'll have no trouble spotting it as dusk deepens.

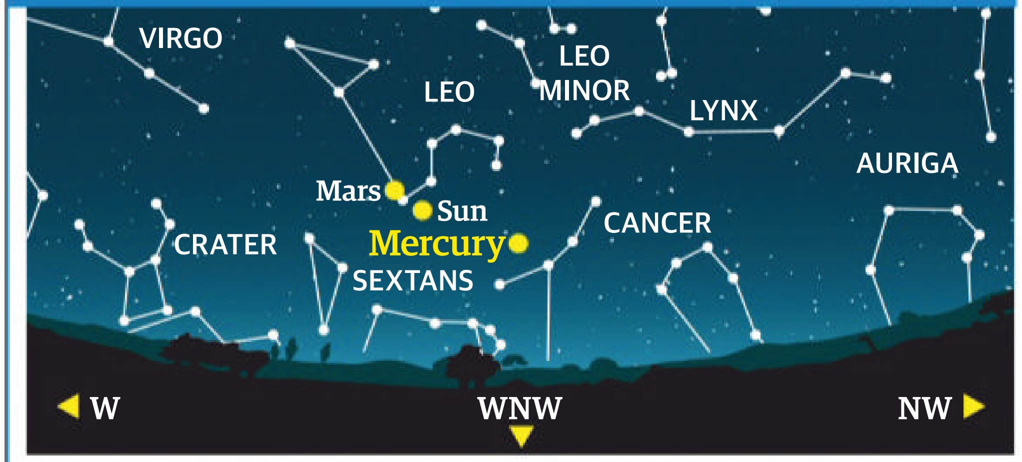
You'll also notice two other stars close to it. To Jupiter's lower right, even closer to the horizon, you'll see orange-red Antares, the brightest star in Scorpius. 30 degrees over to Jupiter's left you'll notice a yellow-white star, fainter than Jupiter. This 'star' is actually the planet Saturn.

In early September Jupiter will have a close encounter of the celestial kind with the Moon. On the evening of the 5th the first quarter Moon will be shining to the right of Jupiter, and on the following night it will be shining to its upper left. Shining close together, the two should offer a beautiful sight through binoculars.

If you have a telescope it will show you features on Jupiter that a pair of binoculars can't. You'll see the planet's squashed disc crossed with dark cloud bands, toffee- and caramel-hued against the planet's creamy disc. You might also glimpse the famous Great Red Spot, a huge storm that used to be as big as four Earths but has shrunk considerably in recent years. In fact, at the time of writing Jupiter observers were worried that it might be about to vanish altogether; it was being distorted and ripped apart by other storm systems passing it. Who knows - by the time you look for it on a warm August or September evening, the Great Red Spot might have completely disappeared.

This month's planets

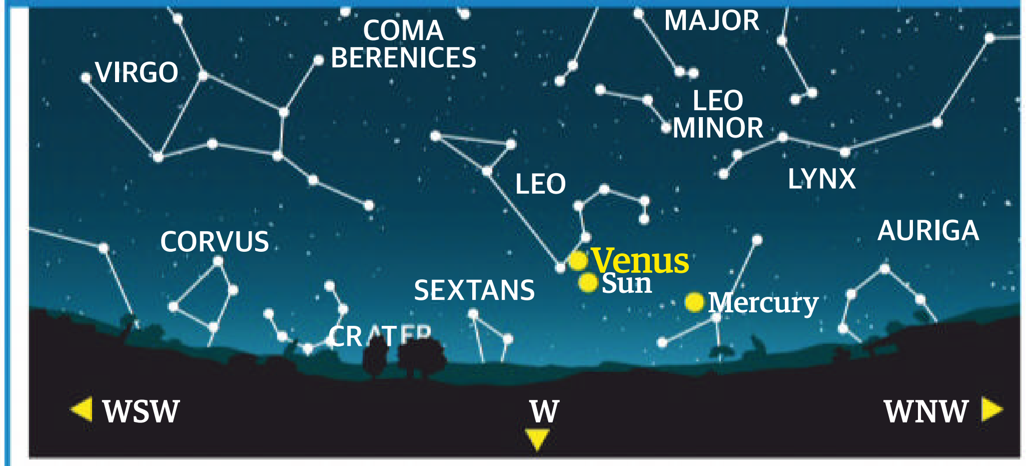
Mercury 18:15 BST on 20 August



Constellation: Cancer
Magnitude: -0.5
AM/PM: AM

At the start of our observing period you might be able to sneak a sighting of Mercury, but it will be very challenging: the closest world to the Sun, which swoops around it once in just 88 days, is technically a morning object, but is so close to the Sun that it will be very low in the sky at around four in the morning.

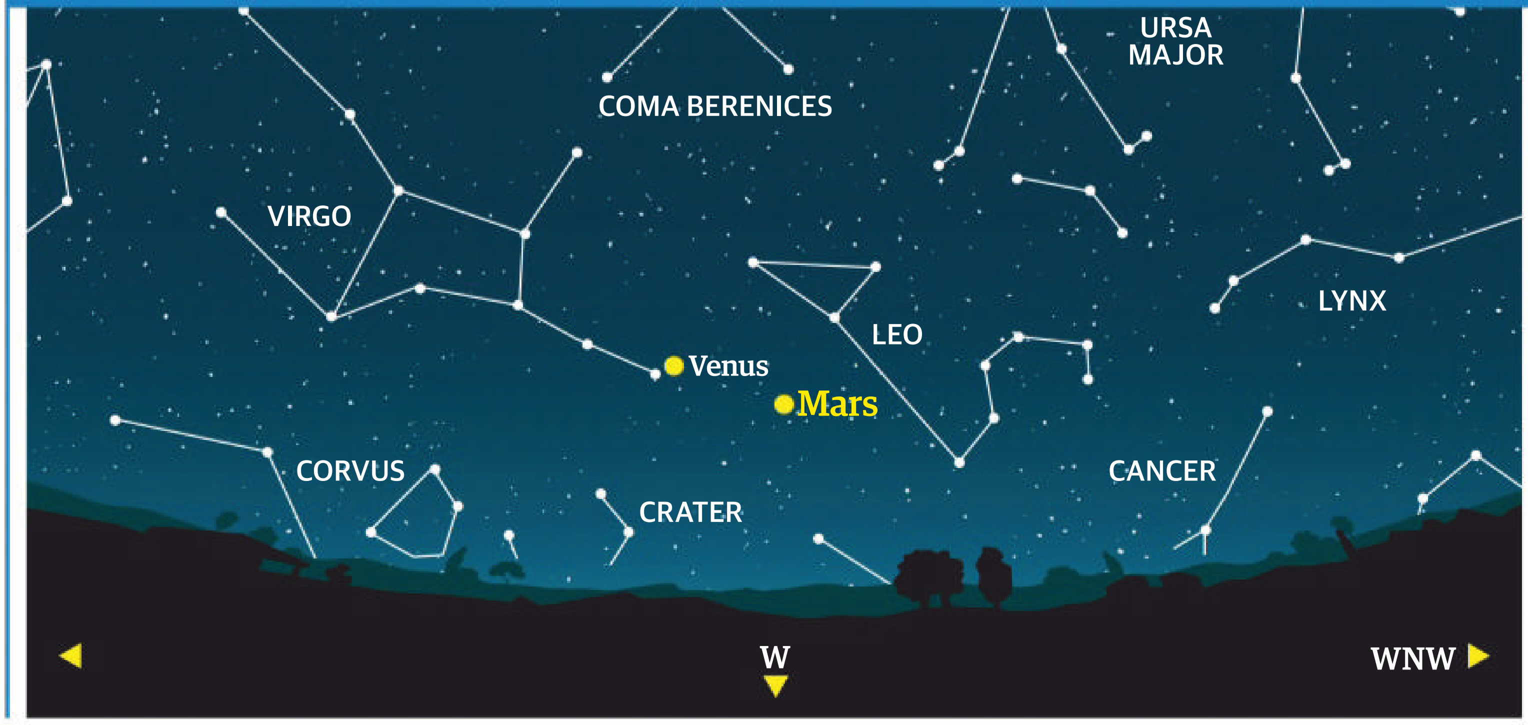
Venus 19:00 BST on 19 August



Constellation: Leo
Magnitude: -3.9
AM/PM: PM

Venus is not visible because it will be too close to the Sun. By the second week of September this deadly world will be an 'evening star' very low in the west after sunset. By then, if you have a pair of binoculars you'll be able to see Mercury close to brighter Venus, but you must wait until the Sun has set to protect your eyes.

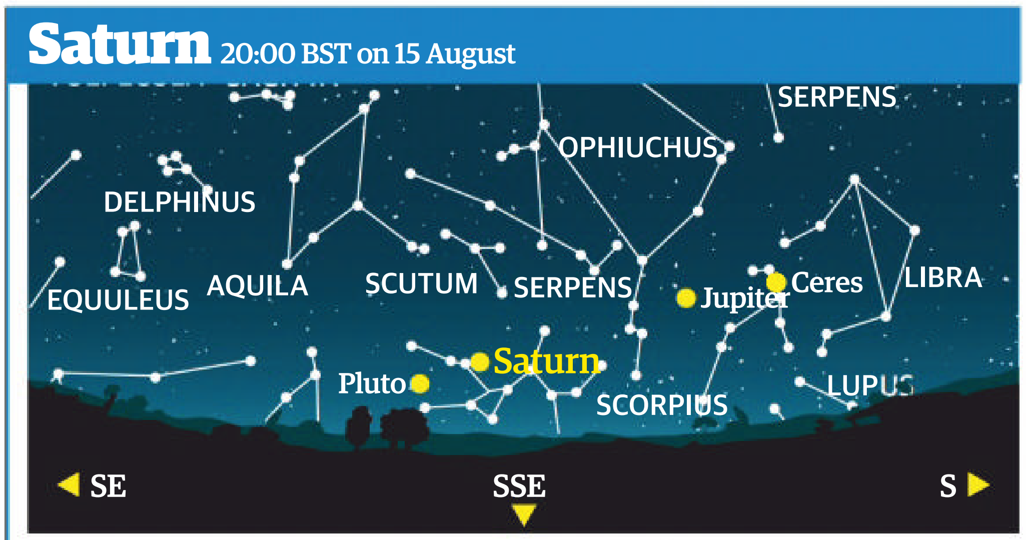
Mars 18:00 BST on 11 September



Constellation: Leo
Magnitude: 1.8
AM/PM: PM

This is going to be a poor month for you if you're a Mars observer. All through our observing period the famous Red Planet is just too close to the Sun to be visible, and not even carefully scouring the pre-sunrise or post-sunset sky with binoculars or a telescope will help. If you want to see Mars this month you'll have to do it through the unblinking eyes of NASA's Curiosity rover, which takes gorgeous pictures of the rolling plains, water-tumbled rocks and layered mountain inside Gale Crater every day and beams them back to Earth for everyone to see online on the mission's website, for free.

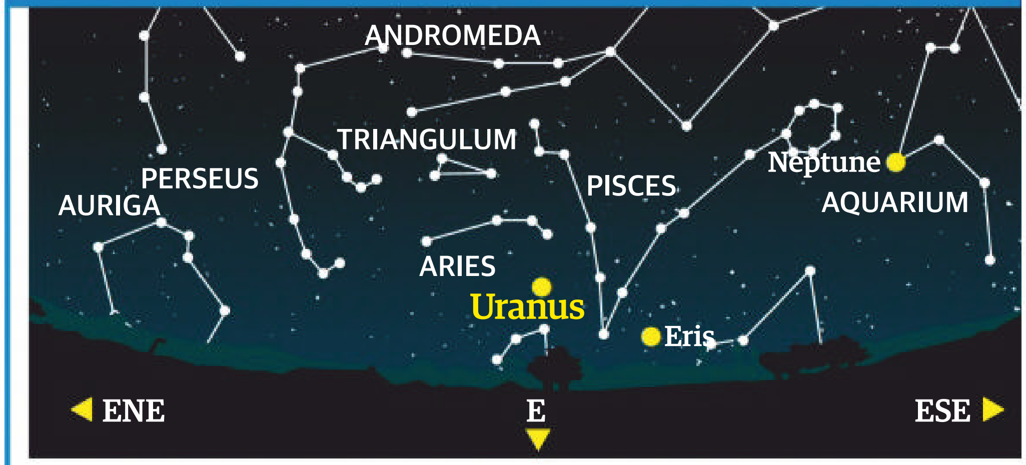
Saturn 20:00 BST on 15 August



Constellation: Sagittarius
Magnitude: 0.2
AM/PM: PM

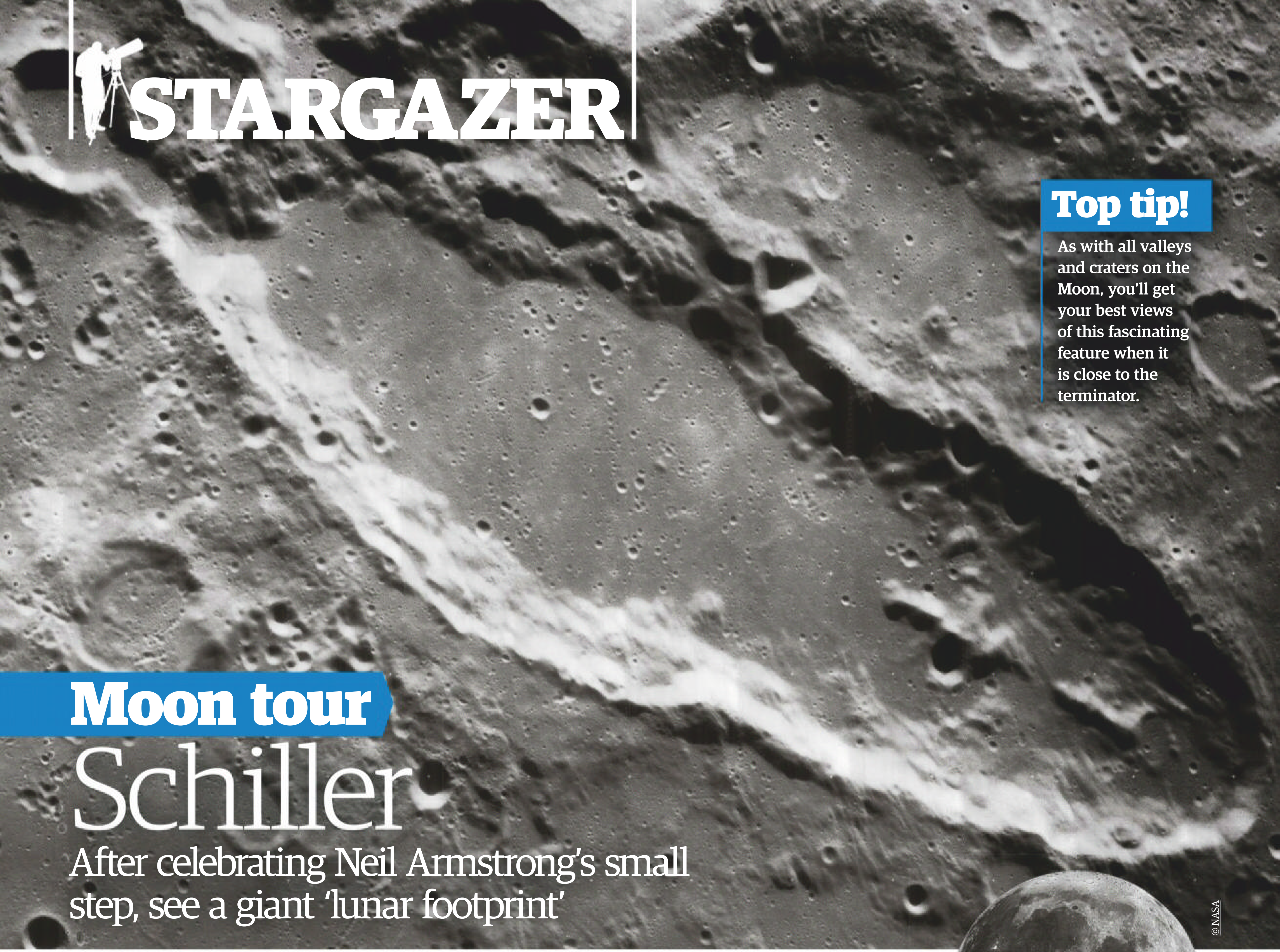
Saturn becomes visible in the east after sunset as soon as the sky begins to darken, and then will arc across the sky through the night, fading as dawn approaches. To the naked eye it will look like a warm, yellow-white star low in the sky, some distance over to the left of much brighter, blue-white Jupiter.

Uranus 22:30 BST on 7 September



Constellation: Aries
Magnitude: 5.7
AM/PM: PM

Uranus is the most distant planet in our Solar System visible to the naked eye - but only just. At magnitude 5.7 it is technically just bright enough to be seen without assistance. At the start of our observing period Uranus will rise in the ENE around 22:30, then slowly cross the sky, fading from view as the sky brightens before sunrise.



Moon tour

Schiller

After celebrating Neil Armstrong's small step, see a giant 'lunar footprint'

© NASA

Top tip!

As with all valleys and craters on the Moon, you'll get your best views of this fascinating feature when it is close to the terminator.

It was fun while it lasted, but the 50th anniversary of the Apollo 11 mission is now behind us. Soon Apollo will revert back to being a historical event, as distant to some as the end of World War II or the Queen's coronation, and in schools across the country - and across the world - children will learn about the glory days of Apollo in the same way they learn about the times of the Victorians or the Vikings.

So, half a century after Neil Armstrong took that "one small step", let's take a look at another footprint on the Moon - or at least a lunar feature that observers think looks like one...

The most casual glance at the Moon through a telescope - or even a pair of binoculars - will reveal its surface is covered with craters, holes blasted out of the Moon by asteroids that slammed into it at incredible speed and with incredible force. Some are huge, more than a hundred kilometres across and surrounded by systems of bright rays of dust and rock that splashed away from them when they were formed. But there are countless numbers of smaller craters. Most have one thing in common: they are roughly circular. However, a few rebel craters aren't circular. They just look... strange.

Our tour destination this issue is Schiller, a 179-kilometre (111-mile) long, 71-kilometre (44-mile) wide impact feature down near the Moon's southwestern limb, not all that far from the bright, ray-sploshed crater Tycho. It can't be seen with the naked eye. You might glimpse it through a powerful pair of binoculars, but really you'll need a small telescope to see it. On a night when the air is still and the astronomical 'seeing' is good, Schiller will look more like a gouge or a long pit than a crater. This is because, being so far south and so close to the Moon's limb, we see it at quite an oblique angle, so it appears foreshortened. But it genuinely is an elongated feature: photographs taken by the Apollo astronauts and later by orbiting survey satellites as they passed over Schiller show why it is so often described by experienced Moon-watchers as being 'lozenge-shaped' or, as we said earlier, a footprint - albeit the footprint of someone with long, skinny feet!

When the Moon is full Schiller is quite hard to find, but when the Sun is hitting Schiller at an angle it really is a fascinating sight. Then, through a telescope using higher magnification, Schiller offers the lunar observer a visual feast. Its rim is very sharp and well defined, and its impressively high walls, which rise some four kilometres (2.5 miles) from its floor, are cut along with stacked terraces, shelves and ledges. At its western end, two mountainous ridges jut up from the centre of Schiller's floor, neatly splitting that half of the crater in two. The floor of the other half to the east is much flatter and smoother, a floodplain of ancient lava marked by only a couple of young craterlets.

How did this weird feature form? At first glance the obvious explanation is that Schiller was made when a huge chunk of space debris struck the Moon at a low angle, ploughing a long trench out of its surface, and what a spectacular sight that would have been! However, those detailed images taken from above suggest to some lunar observers that Schiller is not a single crater, but two craters which formed when multiple meteoroids smashed into the Moon almost simultaneously.

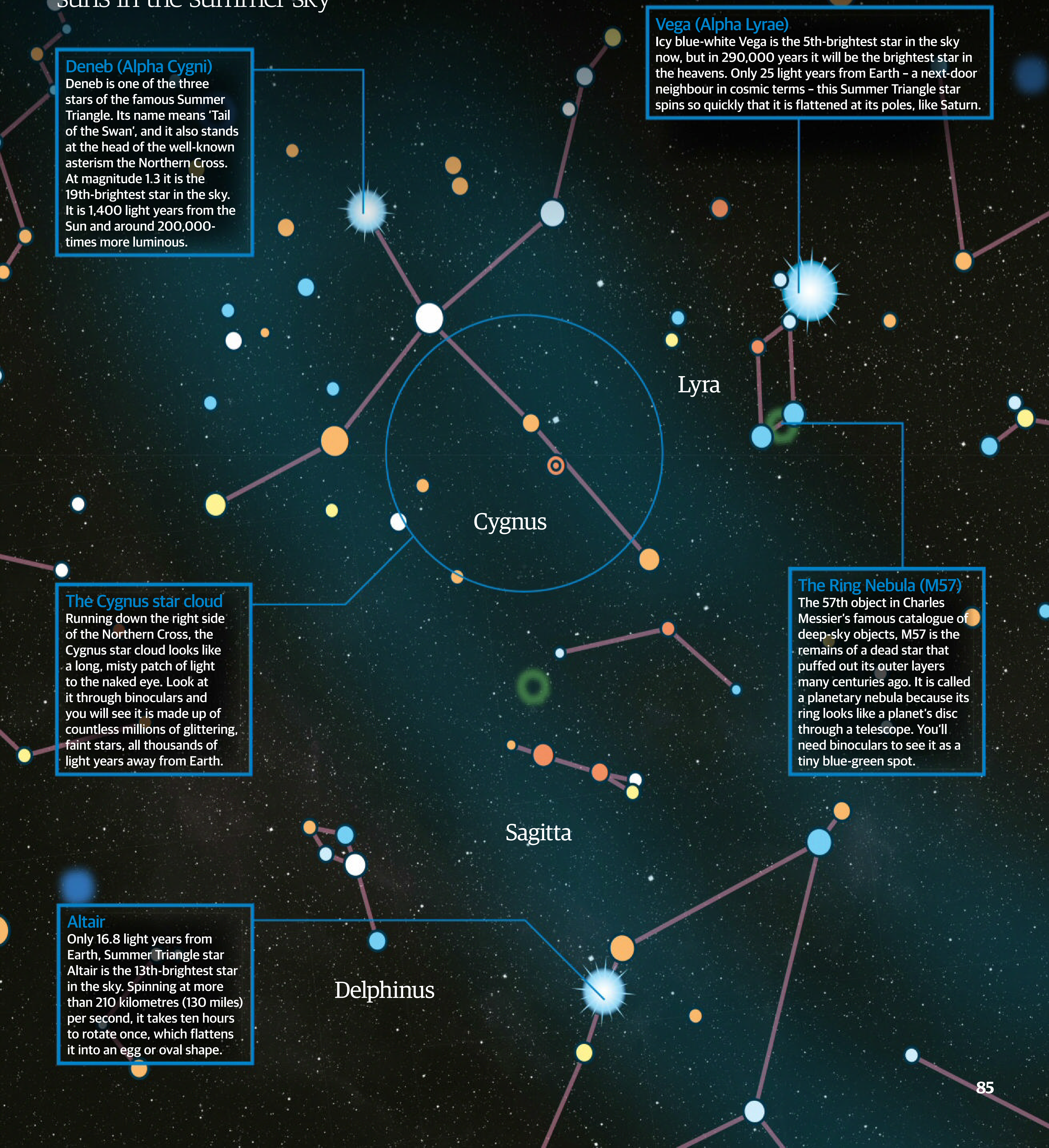
How many? Most probably a pair, but some researchers wonder if Schiller wasn't formed by as many as four separate objects.

However many pieces of space debris created it, Schiller is fascinating to look at. So when can you see it this month?

At the start of our observing period the Moon will be full, so Schiller will be quite hard to see, little more than a bright oval-shaped outline close to the southwestern limb. By 24 August the terminator - the line between lunar night and day - will be approaching Schiller, and it will really stand out from the surface. On 26 August Schiller will be plunged into darkness as the terminator sweeps over it, and we won't be able to see it again until 11 September, when the Sun will rise in its sky and its high walls will cast stark shadows across the lunar surface again.

Naked eye & binocular targets

See a cloud of stars and shells of gas produced by faraway dying suns in the summer sky



Deneb (Alpha Cygni)
Deneb is one of the three stars of the famous Summer Triangle. Its name means 'Tail of the Swan', and it also stands at the head of the well-known asterism the Northern Cross. At magnitude 1.3 it is the 19th-brightest star in the sky. It is 1,400 light years from the Sun and around 200,000-times more luminous.

Vega (Alpha Lyrae)
Icy blue-white Vega is the 5th-brightest star in the sky now, but in 290,000 years it will be the brightest star in the heavens. Only 25 light years from Earth – a next-door neighbour in cosmic terms – this Summer Triangle star spins so quickly that it is flattened at its poles, like Saturn.

The Cygnus star cloud
Running down the right side of the Northern Cross, the Cygnus star cloud looks like a long, misty patch of light to the naked eye. Look at it through binoculars and you will see it is made up of countless millions of glittering, faint stars, all thousands of light years away from Earth.

The Ring Nebula (M57)
The 57th object in Charles Messier's famous catalogue of deep-sky objects, M57 is the remains of a dead star that puffed out its outer layers many centuries ago. It is called a planetary nebula because its ring looks like a planet's disc through a telescope. You'll need binoculars to see it as a tiny blue-green spot.

Altair
Only 16.8 light years from Earth, Summer Triangle star Altair is the 13th-brightest star in the sky. Spinning at more than 210 kilometres (130 miles) per second, it takes ten hours to rotate once, which flattens it into an egg or oval shape.

The Veil Nebula as it appears in ultraviolet

© NASA/JPL-Caltech

Deep sky challenge

Diving deep into the summer sky

This month's targets: the ghostly remains of dead stars, glittering, ancient star clusters and a spectacular galaxy far, far away

Astronomy is, very generally speaking, the study of the stars and everything to do with them - how they are born, live and die; how they work; the objects that go around them and much, much more. The sky in August and September offers the naked-eye observer some of the most beautiful stars in the sky, and the mottled band of the Milky Way too, itself made out of countless billions of stars.

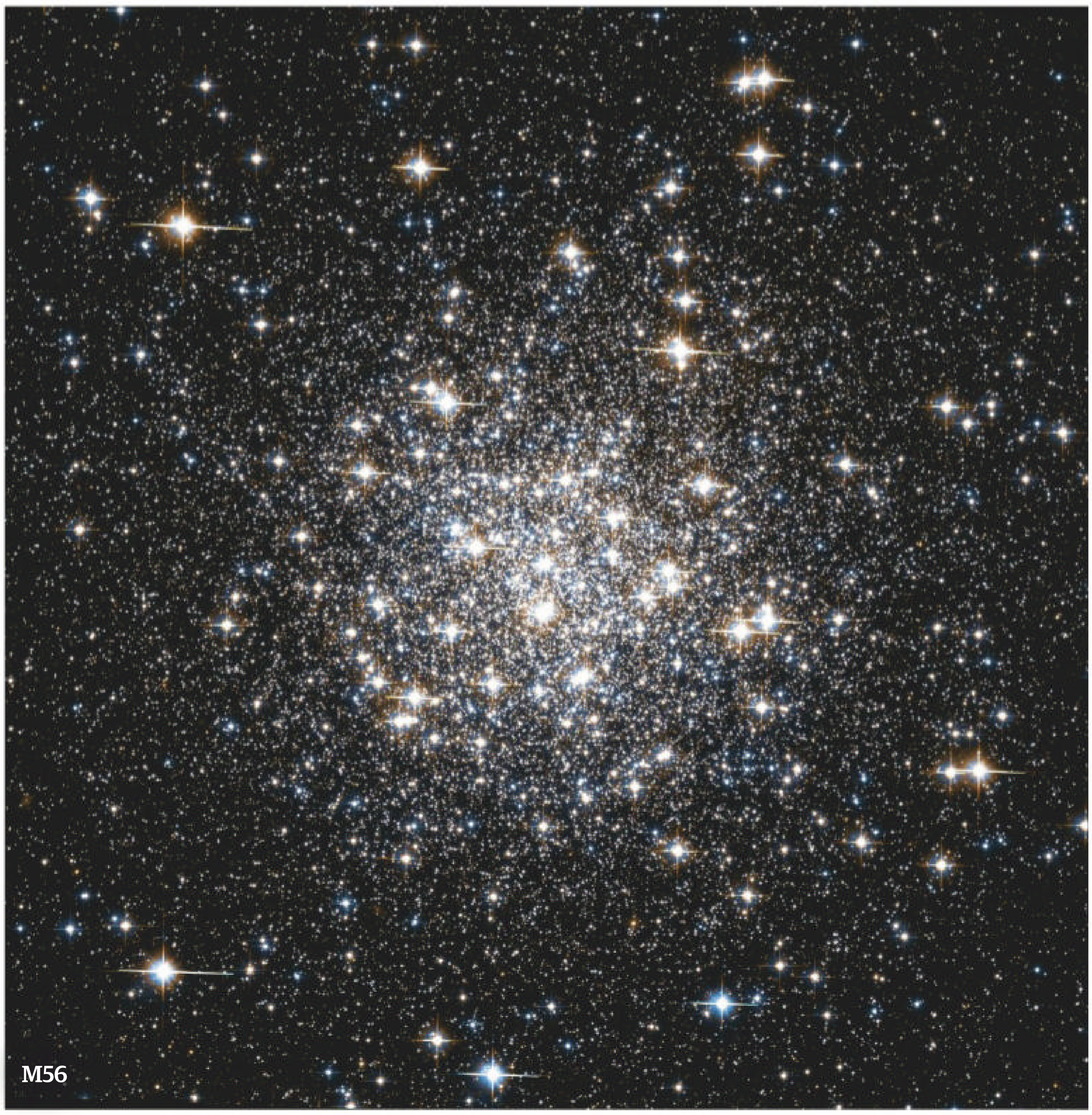
But beyond the stars, through their misty veil, lie objects that are as fascinating as they are faint, as beautiful as they are subtle. Four of our six challenging deep-sky objects this month are nebulae, one is a distant, glittering star cluster and the sixth is another galaxy altogether, an elegant Catherine wheel of stars far beyond the boundary of our own Milky Way. All these objects are going to be a challenge for you if you live somewhere that isn't blessed with a dark sky, and a couple require a large telescope to see them, but they are all worth looking for.

The ghostly, curled wisps of the Veil Nebula are all that remains of a once-mighty star that blew up millennia ago. NGC 6947 is a tightly wound spiral galaxy positively popping and fizzing with star formation. M56 is one of the faintest objects in Messier's famous catalogue - an enormous ball of perhaps a million stars, reduced in a telescope eyepiece to a tiny, smoky ball by its incredible distance. All you need now is a clear night!

The Fireworks Galaxy

© Göran Nilsson & The Liverpool Telescope

Deep sky challenge



© NASA/ESA

1 The Veil Nebula

The ghostly remains of a star that blew up around 8,000 years ago, the Veil Nebula is 5th magnitude, but it is so large and diffuse you'll need a telescope and a dark sky to see its faint, misty arcs.

2 The Crescent Nebula (NGC 6888)

This magnitude 7.4 emission nebula has a distinctive crescent shape in a low-power telescope eyepiece. Around 5,000 light years away, the nebula is best seen using averted vision.

3 Messier 56

One of the faintest globular clusters in Messier's catalogue, magnitude 8.3 M56 can be resolved almost to its centre through a telescope's high-power eyepiece.

4 The Blinking Nebula (NGC 6826)

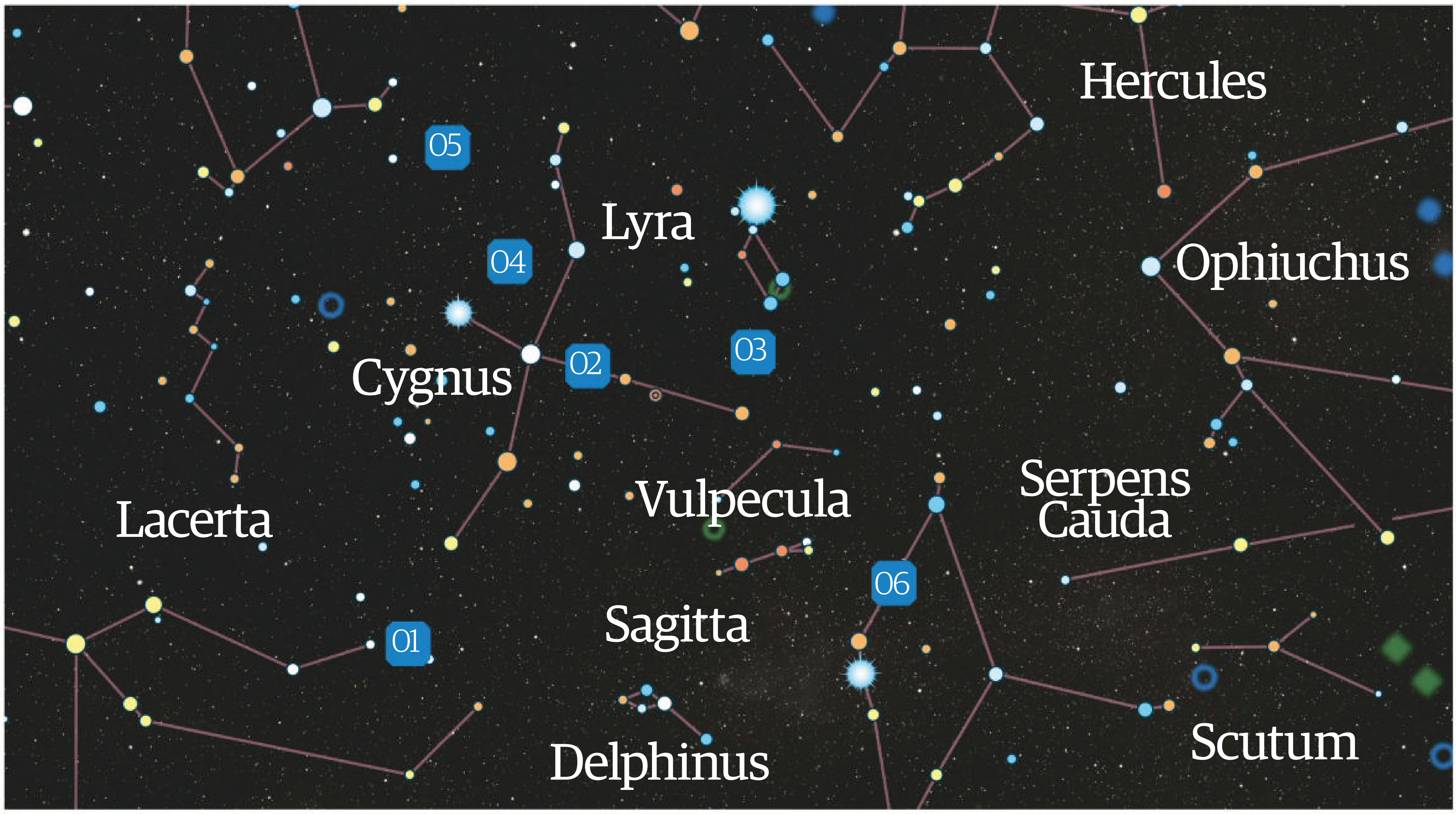
This magnitude 8.9 planetary nebula looks like a small, blue-green oval in a large telescope. Looking at and then away from its central star makes the nebula appear to blink on and off.

5 The Fireworks Galaxy (NGC 6946)

The curved arms of this beautiful face-on spiral galaxy are best seen through the high-power eyepiece of a large telescope. The galaxy is ablaze with colourful areas of star formation.

6 NGC 6803

At magnitude 11.5 this planetary nebula is so faint you'll need a large telescope under a very dark sky to see its tiny, pale blue disc. It is more than 6,000 light years away from Earth.



© Wil Tirion

The Northern Hemisphere

Galaxies, nebulae and star clusters grace the August skies, offering an exquisite selection for stargazers and astrophotographers

Heading into August, there's an impressive array of targets suitable for observers armed with binoculars, telescopes of any size or of which are just content with gazing upon the night sky with the unaided eye.

Galaxies and star clusters are abundant, but it's the nebulae within constellations such as Cygnus and Lyra that are the objects to look to this month. The Ring Nebula (M57), the Pelican Nebula, young and dense planetary nebula NGC 7027, reflection nebula NGC 6914 and the 'blinking planetary' NGC 6826 are particularly impressive, providing observing and imaging opportunities for astronomers and astrophotographers alike.

Using the sky chart

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

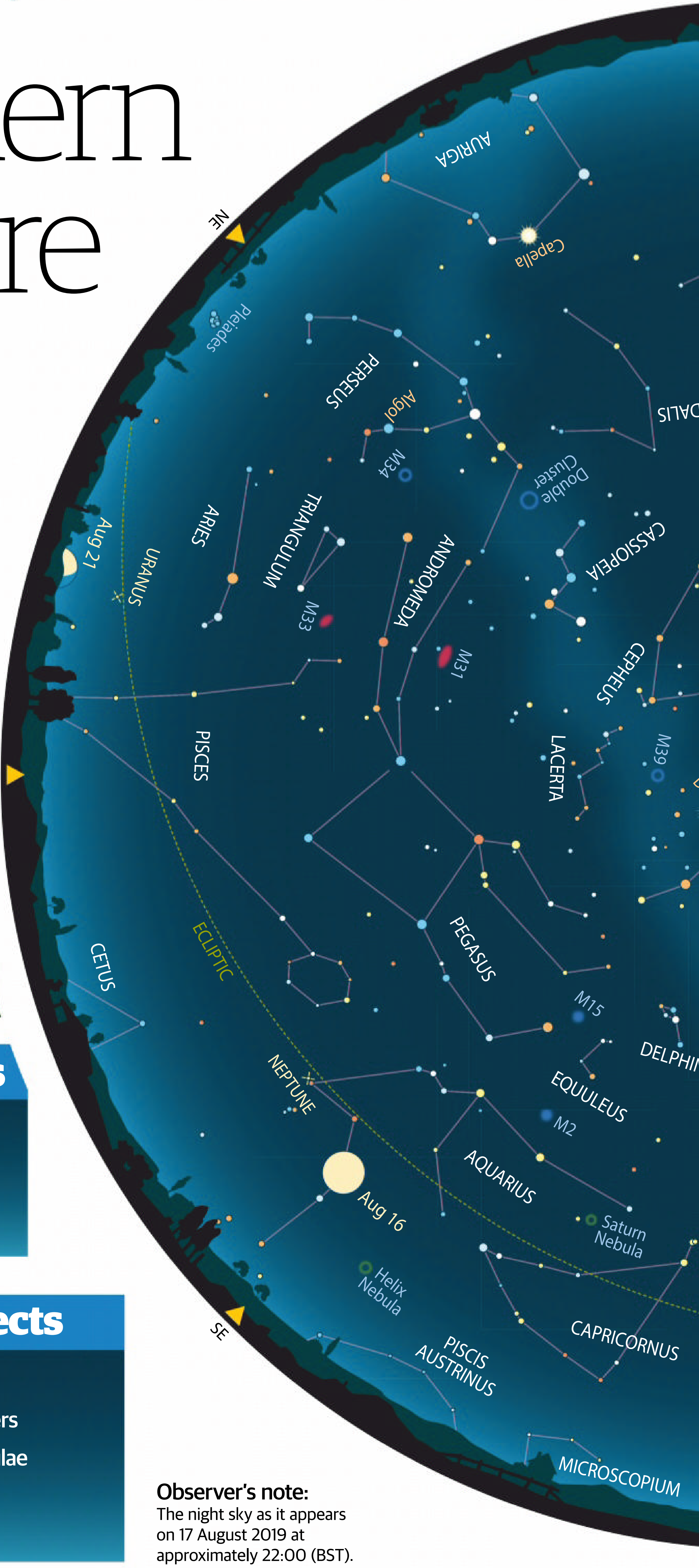
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- ● 1.5 to 2.0
- ● 2.0 to 2.5
- ● 2.5 to 3.0
- ● 3.0 to 3.5
- ● 3.5 to 4.0
- ● 4.0 to 4.5
- · Fainter
- ◉ Variable star

Spectral types

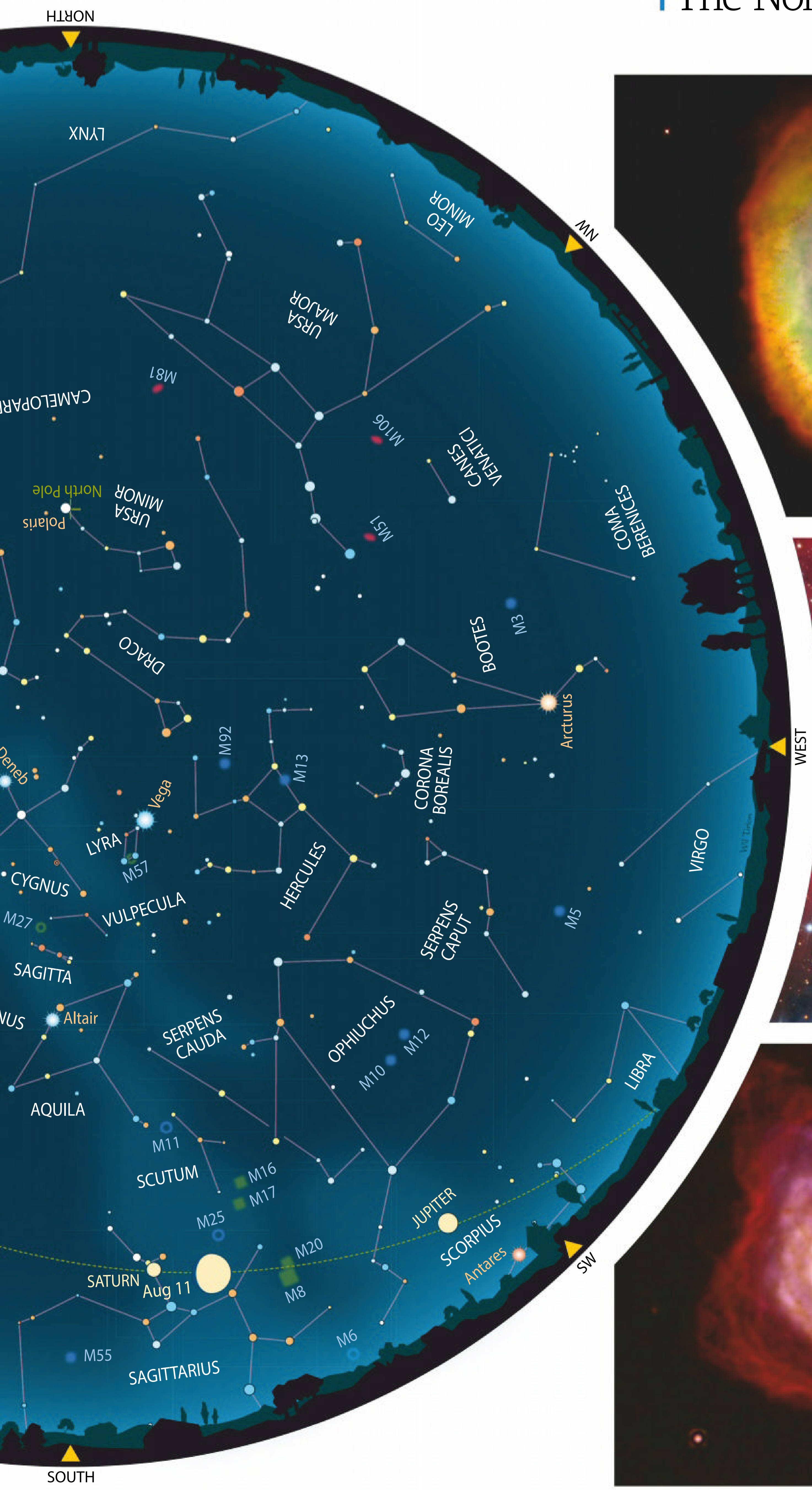
●	O-B	●	G
●	A	●	K
●	F	●	M

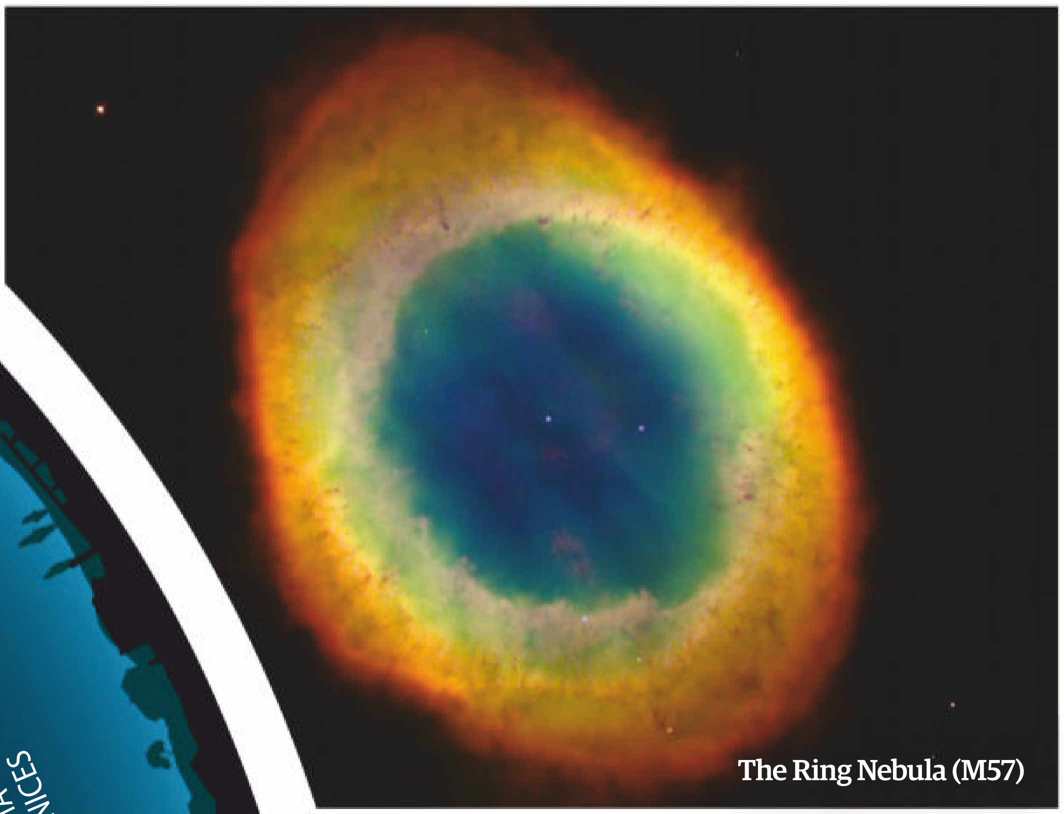
Deep-sky objects

- ○ Open star clusters
- ● Globular star clusters
- 🟩 Bright diffuse nebulae
- ○ Planetary nebulae
- ● Galaxies

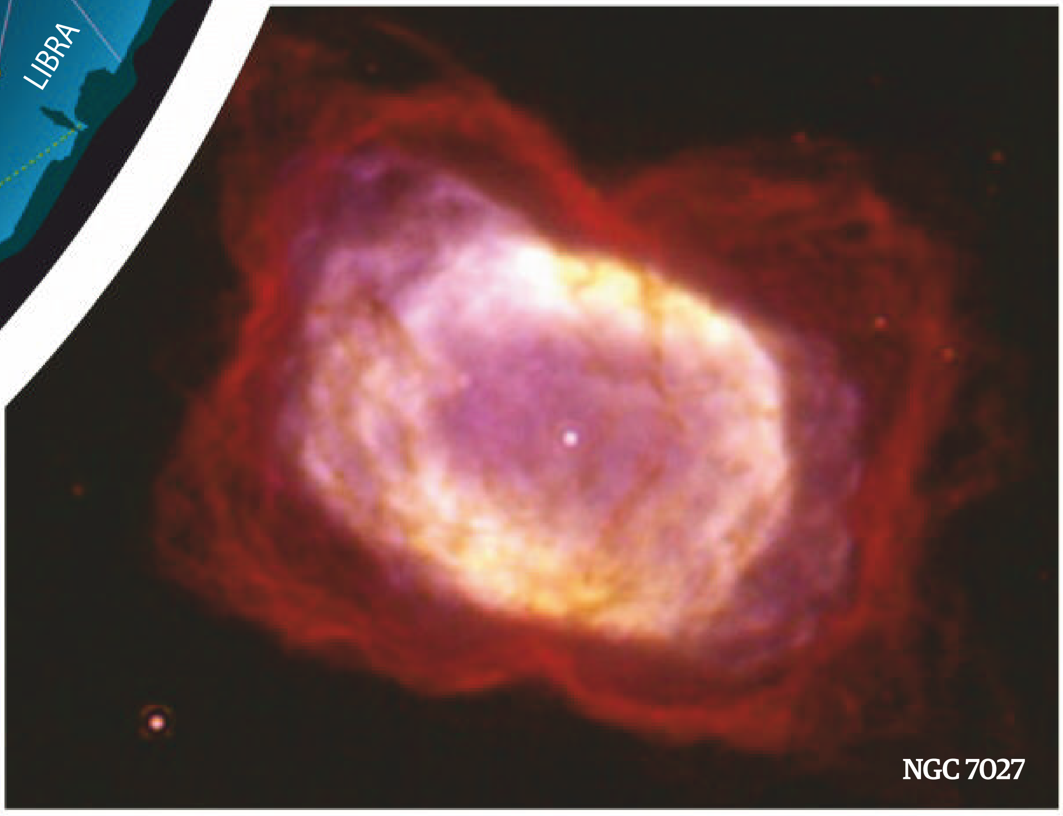


Observer's note:
The night sky as it appears on 17 August 2019 at approximately 22:00 (BST).




The Ring Nebula (M57)

NGC 6914

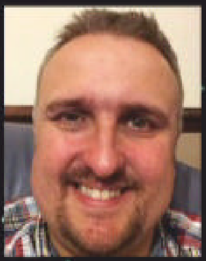

NGC 7027

© Wil Tirion; NASA/ESA; Adam Block/Mount Lemmon SkyCenter/University of Arizona

Astroshots of the month

Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**

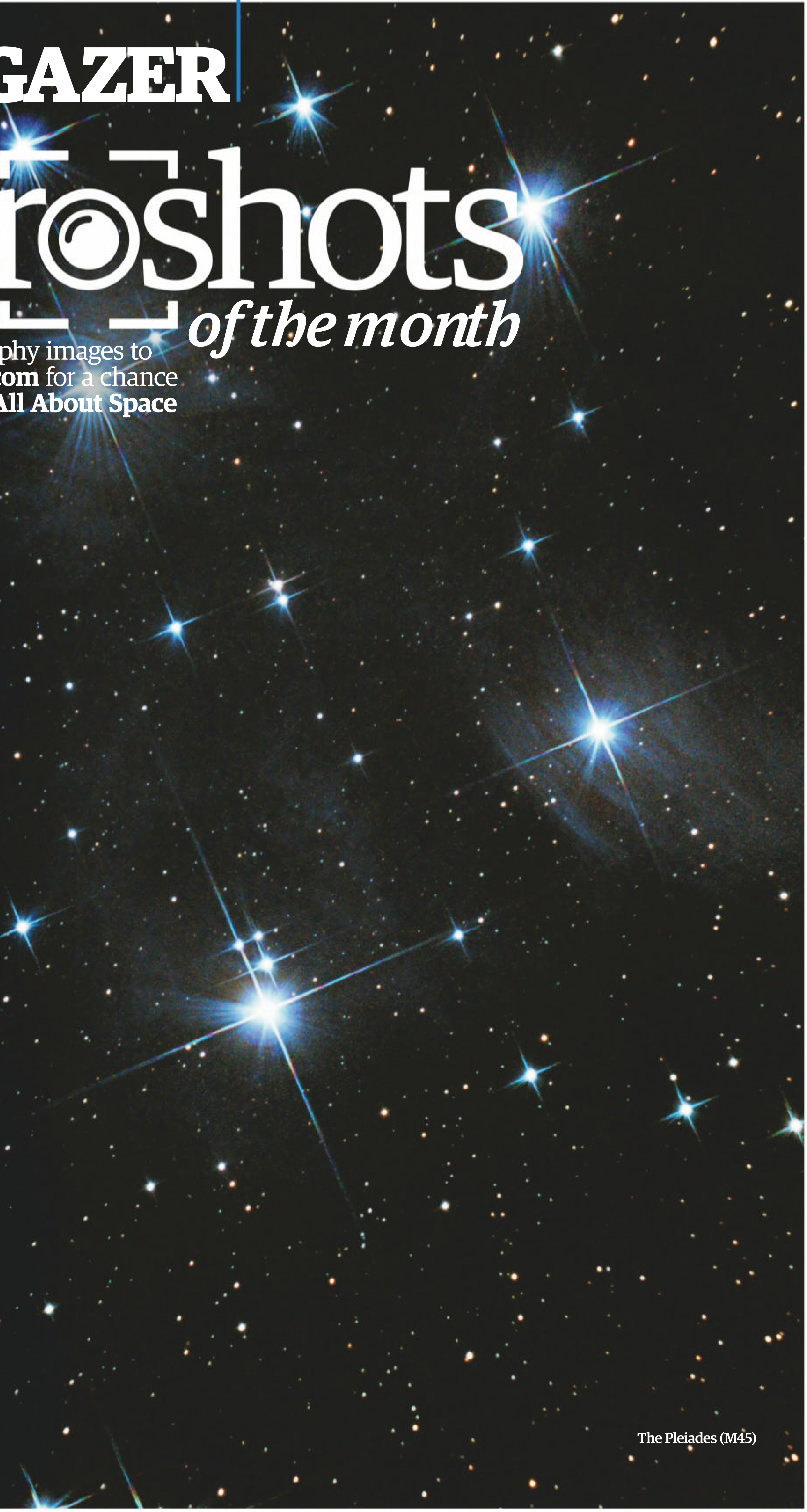
Andy Milner



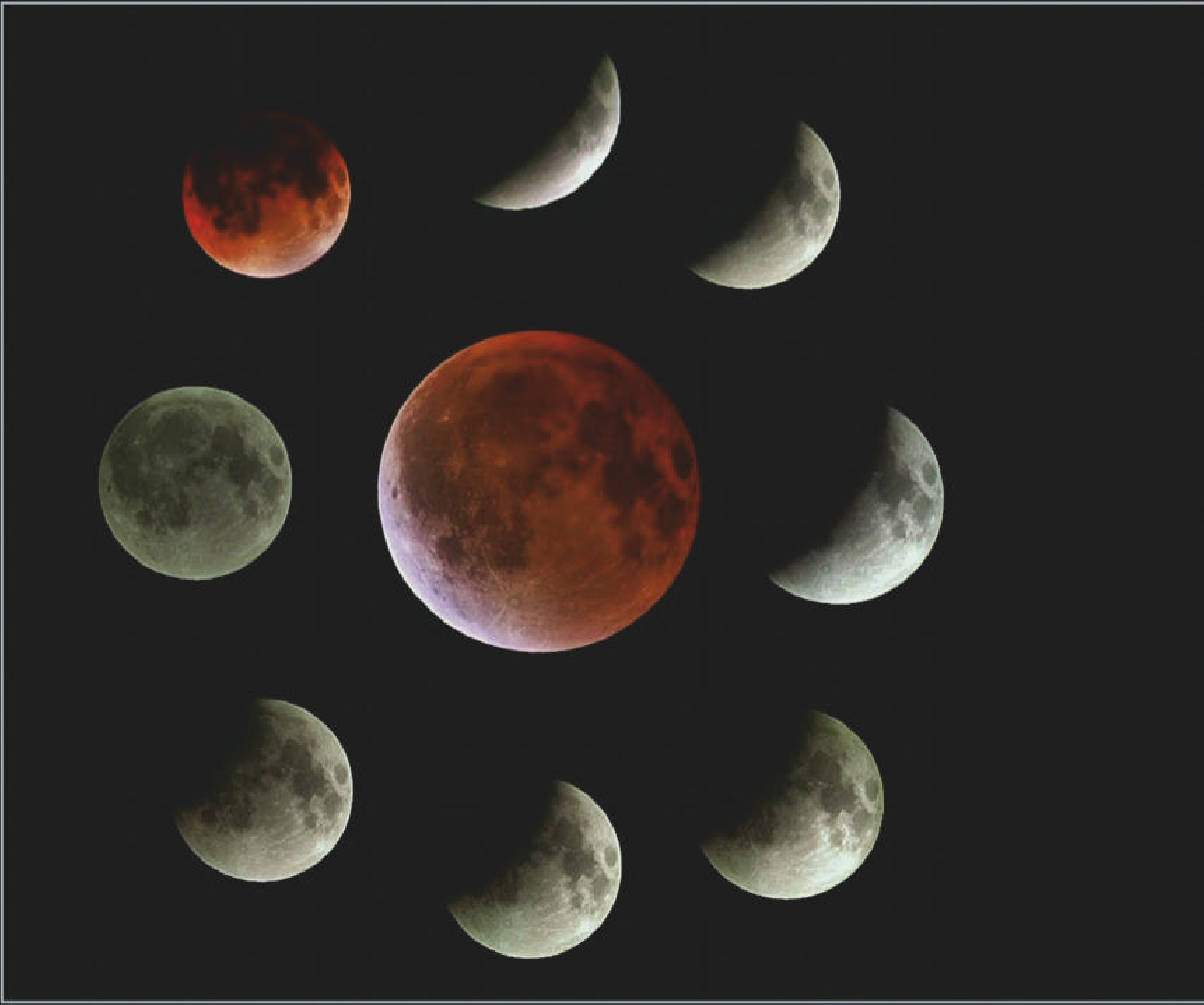
King's Lynn, Norfolk
Telescope: Sky-Watcher Explorer 200P

"I've always been intrigued by the night sky, and decided it's about time I got a telescope. It's been a great journey so far – I've made many friends and gained a huge amount of experience. I am a committee member of my local astronomy society and assist with the admin of online astronomy forums.

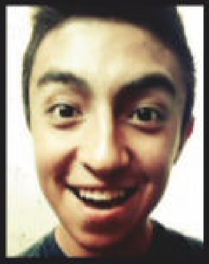
"My passion is astrophotography and I have built up a large range of accessories. My images are either taken with my Canon 1100D DSLR, or with a high-FPS planetary camera."



The Pleiades (M45)



Cristo Sanchez



Yantis, Texas
Telescope:
Orion AstroView 6 EQ reflector

"My passion for astronomy began at the young age of 12. From that point on, I have studied, observed and photographically captured the cosmos.

"Astrophotography is always an exciting thing to do when the skies are clear. Whether it's imaging planets, Messier objects or the Moon, it's always worth the long hours of capturing and processing your images. In the end you get a great feeling seeing the final result and being able to share it with others in the astronomical community, as well as social media."

Collage of a lunar eclipse

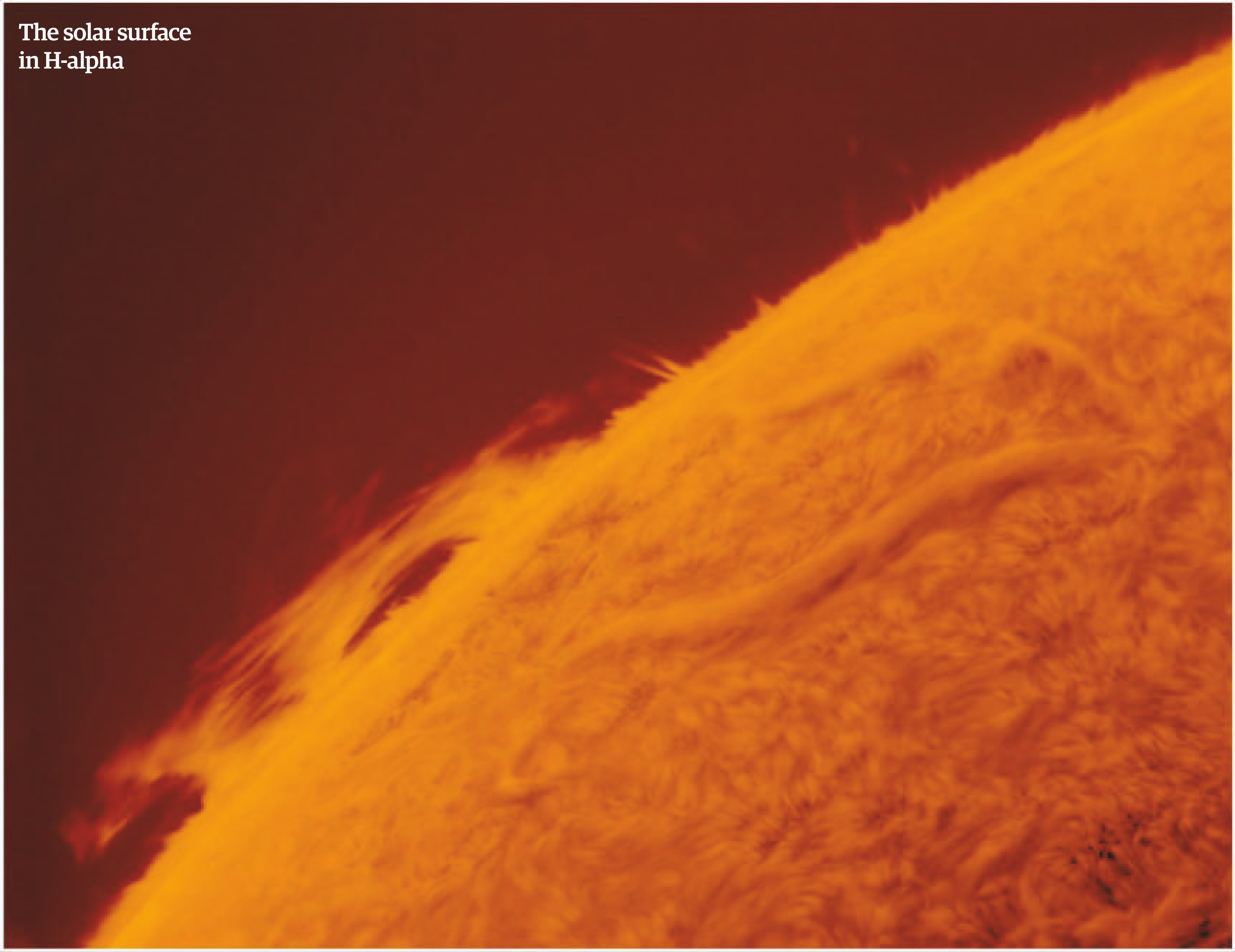
Paolo Porcellana

Castiglione, Italy
Telescope:
150 truss homemade refractor

"When I finally saw through my new telescope after months of waiting, I couldn't believe my eyes – the details and contrast in H-alpha were great, and I enjoyed the view, forgetting to capture more images. The main active region visible that day was captured using my homemade refractor and a PTG Chameleon Mono camera with a DayStar Quantum 0.5A filter. I also produced a negative version to improve on the different details on the Sun's surface.

"Thanks to the brightness of the prominence I could also image details of the disc surface before splitting the post-processing elaboration to reach a comparable level of luminosity and contrast. I then added colour digitally.

"I have been an amateur astronomer since I was 15 years old. I dedicate my free time to the hobby, in particular photography has always fascinated me. I try to experiment with image techniques to reach better results."



The solar surface in H-alpha

Send your photos to... @spaceanswers space@spaceanswers.com

Celestron Inspire 70AZ

An entry-level refractor with a unique design, this telescope is ideal for those on a tight budget who are keen on getting started in astronomy

Telescope advice

Cost: £159 (approx. $195.50)
From: Amazon
Type: Refractor
Aperture: 2.76"
Focal length: 27.56"

Best for...

- Beginners
- Small budget
- Planetary viewing
- Lunar viewing
- Bright deep-sky
- Basic astrophotography

With the darker months almost upon us, now's the perfect time to get started in astronomy. For those who are new to the hobby and would rather spend a small amount of money on a new instrument, the new Inspire range from Celestron meets this criteria. This range of refractors, which became available this autumn, come in a variety of apertures, the 70AZ, 80AZ and 100AZ offering differing light-collecting abilities.

We were impressed with how well packed the Inspire 70AZ was, ensuring perfect showroom condition on arrival. What's more the refractor comes with two 1.25" Kellner eyepieces - 10mm and 20mm - a StarPointer Pro finderscope, an accessory tray, a red LED flashlight, a free download of the SkyPortal app to your Apple or Android device as well as a 90-degree star diagonal - an impressive amount of accessories for a recommended retail price of £130 and everything a beginner needs to get started in astronomy. Handling the tube and tripod as we set the Inspire 70AZ up we found the instrument is very lightweight, promoting portability. While the telescope comes with a very comprehensive manual to assist with the process of setting up, we found it very intuitive to build - something that's sure to delight users keen to get stuck into observing as soon as possible. A free one-year subscription to the SLOOH Astronomer allows the user to remotely reserve, control and image through professional-grade telescopes as well as access to the SLOOH livestream.

Once set up the Inspire 70AZ's appearance is certainly something to be admired - the quality is up to the usual Celestron standard and the manufacturer hasn't skimped on the finish despite the low price, with no glue residue anywhere on the instrument. The design of the tube is somewhat unique, with a fully integrated smartphone adapter that's suitable for basic astrophotography and a hooded dew cap for maximum protection from moisture during observations. The tube's metallic blue-grey finish provides a stylish look that also adds to the telescope's protection from the elements. The steel tripod is well-made, ensuring sturdy observations, and a solid alt-azimuth mount allows the tube to smoothly move through right ascension and declination. The twist-clutch handle does the job for easy tracking of celestial objects. The ball star diagonal does the job of holding the eyepieces, but being made of plastic it's slightly flimsy compared to the rest of the instrument. The integrated accessory tray is a nice touch to the overall build of the Inspire 70AZ - being already attached to the tripod, a simple lock of the knob allows this feature to fit into place. With previous models of telescope we have found fitting the accessory tray to a tripod to be quite a challenge, but with this refractor this is relatively fuss-free.

Below left: The Celestron Inspire 70AZ comes with a selection of accessories, including 10mm and 20mm eyepieces

Below right: Fully coated glass optics provide clear views of the night sky. However, there is a degree of colour-fringing around particularly bright objects

Taking the instrument to begin observations, we were grateful for the telescope's lightness. The supplied diagonal and eyepieces fit the tube nicely, but if you're looking to substitute these with accessories made with a more hefty material, then you'll find that there will be balancing issues, with 'sagging' views.

Refractors are great instruments for observing the Solar System, so we made Jupiter and Saturn in the southwest our targets of choice during a mid-July evening. For a 'scope with a modest aperture, we were impressed with the views of the planetary pair, though we were unable to pick out a great amount of detail on the surface of the king of the Solar System. Saturn, which shone at a magnitude of 1.1, was an impressive sight through the refractor, its fully coated glass optics providing good views of the gas giant and its rings even under slightly hazy conditions. Colour-fringing – also known as chromatic aberration – is minimal when observing objects of modest magnitudes. However, the waning gibbous Moon sported a purple-blue edge in the Inspire 70AZ's field of view, while a Moon filter provided excellent contrast when observing lunar mare, mountainous terrain and craters. Throughout our observations eye relief was good, and the angle of the star diagonal allowed for comfortable tours of the night sky.

The red LED flashlight that's built into the mount came in handy when preserving our night vision during times we had to refer to a night sky guide. Budding astrophotographers will be grateful for the integrated smartphone adapter, which uses bungee cords to secure the phone to the lens cap.

We tested the refractor's mettle on some deep-sky objects such as the Pinwheel Galaxy (M101), a face-on spiral galaxy in the constellation of Ursa Major, and slewed across to the constellation of Taurus to get a rich view of the Pleiades (M45) open star cluster in the early morning sky. Views of deep-sky objects are small through this refractor, but are discernible provided they are bright enough.

Built for terrestrial views as well as celestial, we took the opportunity to observe a bird's nest a few feet away. Views were clear, boasting the telescope's dual uses. With its ease of use the Inspire 70AZ is ideal for those looking to get started in astronomy as well as those who want an instrument built for a multitude of purposes – from observing planets to mountain peaks.

Left: The alt-azimuth mount features a red LED to preserve the observer's night vision

WIN

APOLLO 11 DIE-CAST MODELS

Corgi is proud to reintroduce two Apollo 11 models to celebrate humankind's greatest achievement – we're giving you the chance to win one of 10 sets

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Apollo Lunar Module

As the Apollo space programme attempted to place humans on the surface of the Moon in the summer of 1969, the world held its breath as NASA transmitted sound and pictures from its incredible mission across the globe. Becoming perhaps the most recognised craft to an entire generation of people, the Lunar Module which landed Neil Armstrong and Buzz Aldrin on the Moon on 20 July 1969 represented the pinnacle of human engineering prowess, but could it bring the astronauts home safely? As the Columbia Command Module splashed down in the Pacific Ocean four days later, the world had its answer and three new heroes to honour.

Apollo Command Module

Responsible for carrying all three astronauts and the Lunar Module into lunar orbit, the Apollo Command Module played a vital role in the Apollo 11 landings. The Command Module was 11-metres (36-feet) high and 3.9-metres (12.8-feet) wide, and having taken off from Kennedy Space Center, Florida, on 16 July, delivered its passengers to their destination in just four days. On their return to Earth the three astronauts had to spend 21 days in quarantine to ensure they hadn't contracted a 'Moon disease'. Once finally released a parade and state dinner was hosted on 13 August to celebrate the mission's success. In 1961 President John F. Kennedy had committed to seeing a man land safely on the Moon within a decade, and thus his promise to the world had been achieved.

To be in with the chance of winning, all you have to do us answer this question:

In space exploration, what does CMP stand for?

A: Command Module Pilot

B: Central Module Position

C: Command Module Pioneer

Competition ends on 5 September 2019

Enter via email at
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All About Space competitions, Richmond House,
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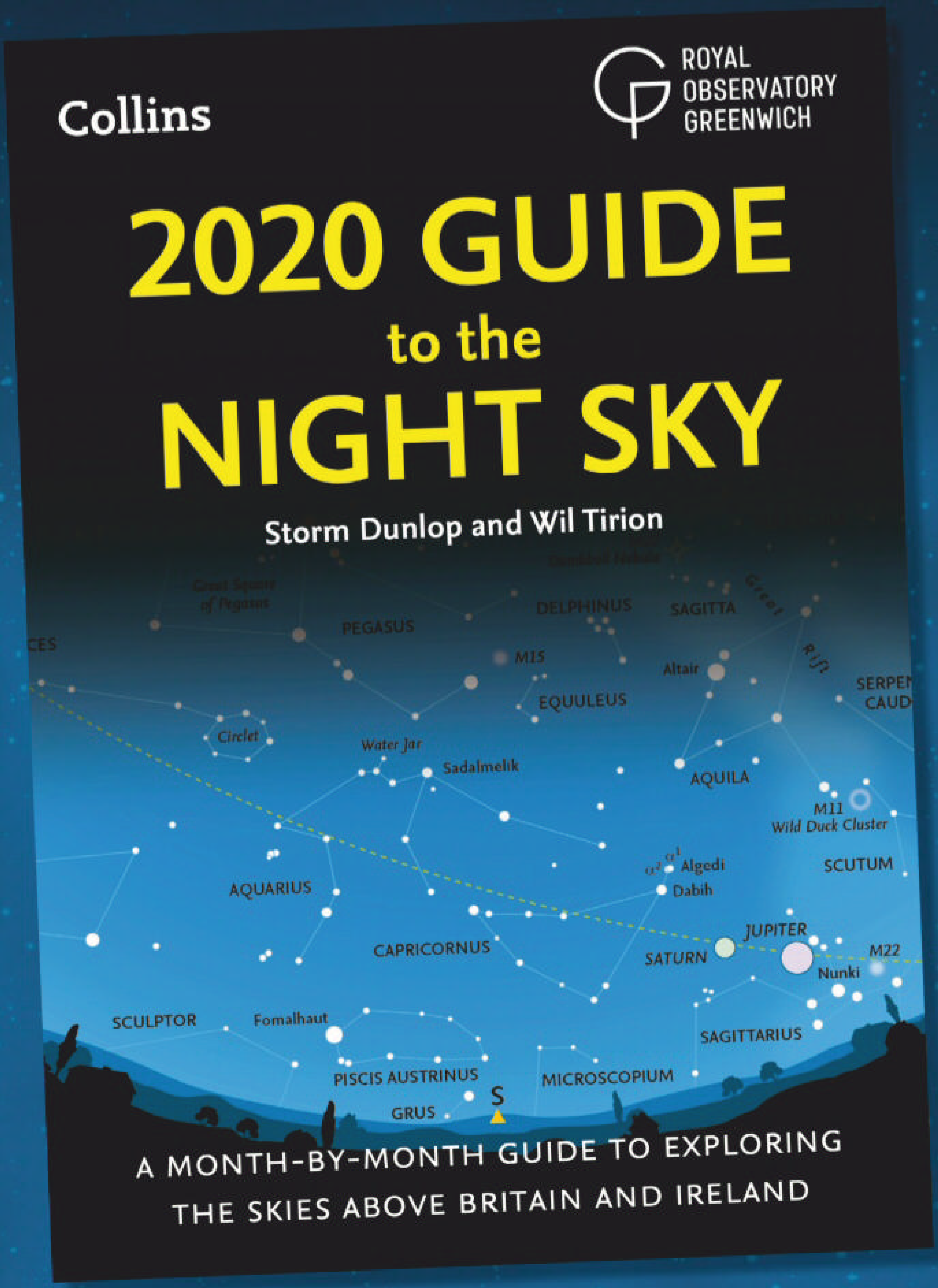
Visit the website for full terms and conditions at **spaceanswers.com/competitions**

Congratulations to Evan Hughes who is the winner of a Meade LightBridge Mini 130!

BESTSELLING MONTH-BY-MONTH GUIDE TO THE NIGHT SKY



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ROYAL OBSERVATORY GREENWICH
2020 GUIDE to the NIGHT SKY
Storm Dunlop and Wil Tirion
PEGASUS
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SATURN
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A MONTH-BY-MONTH GUIDE TO EXPLORING THE SKIES ABOVE BRITAIN AND IRELAND

For all astronomy enthusiasts, from beginner to seasoned stargazer

Includes:

- Advice on where to start looking
- Easy-to-use star maps for each month with descriptions of what to see
- **NEW** Special, detailed charts for positions of planets, minor planets and comets in 2020
- **NEW** Seasonal charts
- **NEW** Details of dark sky sites
- Details of objects and events you might see in 2020

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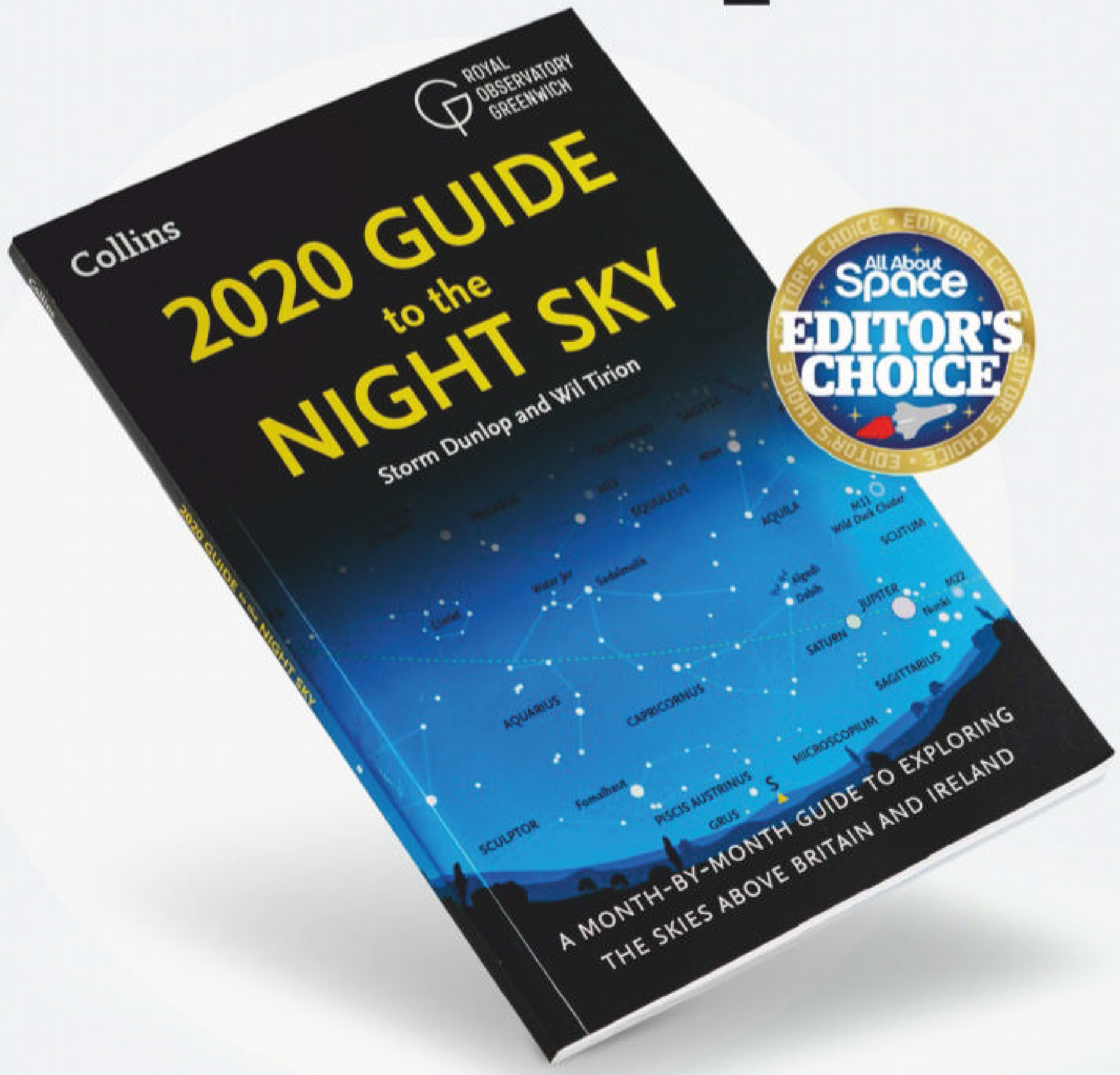
The latest books, apps, software, tech and accessories for space and astronomy fans alike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All About Space
EDITOR'S CHOICE

Book

2020 Guide to the Night Sky

Cost: £6.99 (approx. $8.50/€7.60)
From: HarperCollins

The bestselling practical guide to the planets, stars and constellations visible from the Northern Hemisphere, the *2020 Guide to the Night Sky* is your complete reference to what's visible in the night sky from January through to December 2020. The *2020 Guide to the Night Sky* is an easy introduction to astronomy for those just starting out in the hobby, but it also serves as a useful reference for those who are much more seasoned in observing the heavens.

The book is wonderfully written and illustrated by astronomers Storm Dunlop and Wil Tirion, providing advice on where to start looking, details of objects and must-see events in 2020 and in the newly revised edition for this year, special detailed charts for positions of planets, minor planets and comets and details of dark-sky sites from which to get the very best views of the skies above.

The *2020 Guide to the Night Sky* is usable anywhere in the world between latitudes 40°N and 60°N, covering most of Europe, southern Canada and northern parts of the United States.

App

SkEye Pro

Cost: £4.73
From: Google Play

An advanced planetarium for the astronomer, whether you're a beginner or have been touring the night sky for years, SkEye is the perfect companion for navigating the night sky. What's more this app - which can be downloaded to any Android device - is unique in the sense that you can strap it to a telescope or a pair of binoculars, allowing you to tour the night sky with the app and your instrument combined. A 'simple' version of SkEye is also available as a free app for Android and Kindle Fire HD users.

SkEye's interface is smooth, as is its ability to track objects in the night sky. It's also quick at finding your favourite targets and, in comparison to other free apps, SkEye is very good at geo-aligning with accuracy and ease - something that beginners to astronomy will be extremely grateful for.

In an attempt to cater for a wide audience it has its drawbacks. Many of the Messier objects we found didn't have a great deal of information about them built in, something that may put off some users. If this doesn't bother you, SkEye certainly holds its own when navigating the night sky.

Software

Starry Night 8

Cost: Starting from $149.95 (approx. £122.75/€134.70)
From: starrynight.com
Dubbed 'the most realistic astronomy software', Starry Night 8 certainly lives up to the hype. Its graphical performance as well as its huge package of options that contains everything the serious astronomer needs makes this a must-own by those keen on the wonders of the night sky. If you are still learning your way around the sky, then we advise purchasing a more simplistic astronomy software.

Starry Night 8, which is available for Mac and PC, comes with a wide selection of objects – including 16 million stars, over 19 million objects up to magnitude 15 as well as 73,197 galaxies along with their three-dimensional positions. Starry Night 8 is also massively educational and, provided you have QuickTime installed on your computer, you can watch a wide selection of movies, including sky animations, planet flybys achieved by NASA missions and rocket and spacecraft launches. This astronomy software also allows you to travel beyond the Solar System up to 700 million light years away and create planets with customisable surface details and satellites. You can also go back or forward in time by 99,999 years to observe the sky and track asteroids and comets.

Given its massive amounts of data, Starry Night 8 requires a computer with a large amount of RAM and hard disk space. If this doesn't worry you and you have had an interest in astronomy for a long time, then we can strongly recommend this program.

Binoculars

Meade Instruments Mirage 7-15x35 Zoom Binoculars

Cost: £75 (approx. $91.60/€82.30)
From: Hama UK Ltd
With fully multi-coated optics and porro prisms, these binoculars possess impressive viewing capabilities and an adjustable zoom that opens up a brand-new perspective. Bright, high-resolution views are supplied as standard from the high-quality optics, making them ideal for a multitude of sports and leisure activities such as birdwatching, hiking or sightseeing, with commendable performance even in low-light conditions.

The toughened-rubber armoured outer shell provides impact protection and improved grip when on the go, while the provided cleaning cloth effectively removes any dirt that may be accumulated on the road, leaving you to continue to enjoy entirely unimpeded views. Centrally located, the Mirage's easy-access focusing mechanism permits straightforward fine-tuning of the view, further aided by the eyecup-mounted dioptre knob. Fold-down rubber eyecups guarantee eye glass wearers their equal share of the spectacular views, testament to the outstanding comfort and versatility of the Meade Mirage for all users.

NASA's Mission Control Center has been operating for over 50 years in support of space missions

©NASA

Christopher C. Kraft

NASA's first flight director and sculptor of Mission Control

It's a room that has held the tensions of engineers, astronauts and other employees of NASA for decades: Mission Control at the Johnson Space Center in Houston, Texas. The man behind this historic establishment was Chris Kraft, who played a vital role in the history of NASA.

Christopher C. Kraft Jr. was born on 28 February 1924 in Phoebus, Virginia. His early years were not centred around aviation, as many of the stories go for the astronauts during the Mercury, Gemini and Apollo programs. Mechanical engineering came first, which he studied in 1941 at the Virginia Polytechnic Institute. During this time he experienced the workings of the military Corps of Cadets, and he claims it was these experiences that sculpted the personality that gave him great success at NASA.

During the rise of the jet age in the 1950s, Kraft became interested in aviation. Unfortunately he had sustained burns when he was just three years old that deemed him physically incapable for military service. Instead he made his trade in engineering, and with that came the role of project engineer on high-priority test flights for the US Navy.

In November 1958 NASA had assembled its Space Task Group, consisting of 35 members that were tasked with managing the United States' manned spaceflight programme. It was headed by Robert Gilruth, who Kraft had known from his days at Langley Memorial Aeronautical Laboratory over a decade prior. Gilruth presented an invitation to Kraft, which he accepted, and he was thrown into the responsibilities of the first ever flight director, putting into place the mission procedures and sorting operational issues that came along with the manned spaceflight programme.

Kraft's career then moved from research engineer to manager of engineering and organisation. Along with developing the mission procedures that would see NASA's manned spaceflight programme prosper and overtake the Soviet Union in the Space Race, he was also a key participant when it came to overseeing the construction of NASA's new Manned Space Center (MSC) – what is now known as the Johnson Space Center .

Kraft served as flight director during the historic early moments of the spaceflight programme, which included the successful sub-orbital and orbital flights of Project Mercury and the first spacewalk of the Gemini program. Afterwards he served as director of flight operations at the MSC, still proving vitally important in the most successful period of spaceflight through to Apollo 12 in 1969. He took other roles afterwards, which saw him serve in the remaining Apollo missions, the Skylab space station construction, the Apollo-Soyuz space docking and the first flights of the Space Shuttle program.

For his efforts Kraft obtained many awards, including the NASA Outstanding Leadership Medal, four NASA Distinguished Service Medals, and the Distinguished Citizen Award, given by the City of Hampton, Virginia. All of these efforts are detailed in his autobiography, *Flight: My Life in Mission Control*. Sadly, Kraft passed away on 22 July 2019, just after celebrating 50 years since Apollo 11.

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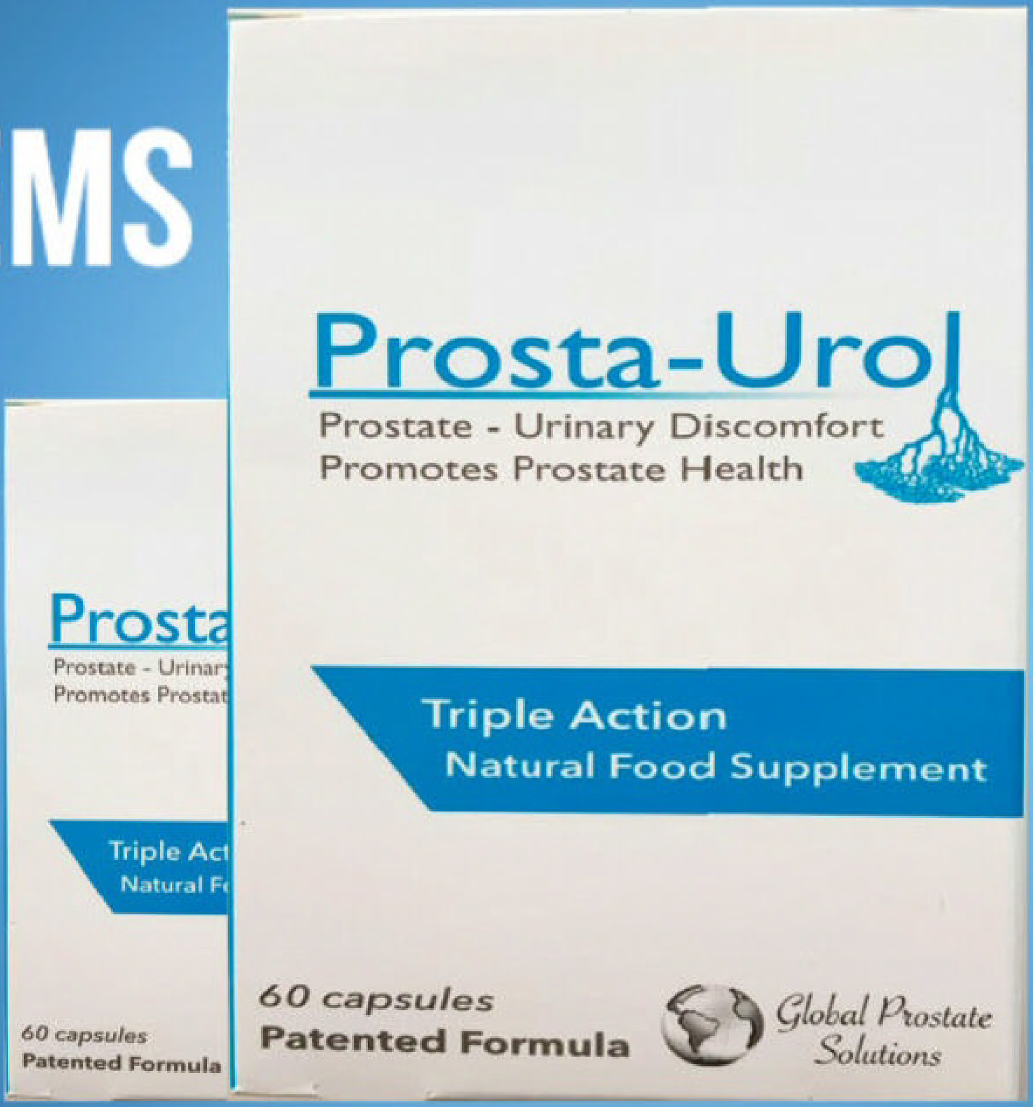

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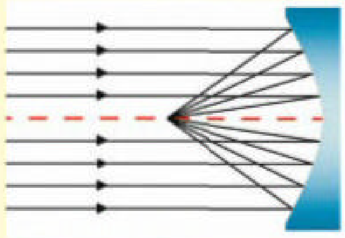

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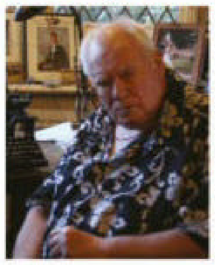

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